Cassidulinidae (Foraminiferida) from the Uppermost Cenozoic of Japan (Part 1)

Tohoku Univ., Sci. Rep., 2nd ser. (Geol.), v. 53, no. 1, p. 1–101, 60 figs., 1 table, pls. 1–25, February 25, 1983.

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ABSTRACT

The family Cassidulinidae from late Cenozoic sediments of Japan is examined by means of optical and electron microscopes. Among the total of 76 taxa including species and subspecies, 24 species and 2 subspecies are described as new. Three new genera *Takayanagia*, *Paracassidulina* and *Hastilina* are also proposed.

For the taxonomic classification, various external and internal characters including wall microstructure, internal structure, aperture, perforation, and test ornamentation are re-evaluated with particular emphasis placed on problems concerning the formation and function of these features. In considering these features, family Islandiellidae Loeblich and Tappan belonging to the superfamily Buliminacea is abandoned. Many genera which have been included in that family are now transferred to the family Cassidulinidae.

The test walls of the Cassidulinidae are composed of three calcitic structural components, outer veneer, crystalline structure, and inner veneer. Four major types of pores are recognized; the shape of pores on the external test surface is regulated by the outer veneer and successive growth lamellae.

External and internal apertural modifications such as toothplate, lip, and plate are examined in detail, which necessitated the redefinition of their structural features. Nine basic apertural forms are recognized, which are important to the determination of generic relationship.

Based on the differences in structure of crystal units, four types of basic test structure can be recognized in the optically radial and granular textures. These are fibrous crystalline structure, bundle-shaped crystalline structure, intricate crystalline structure, and clumpy crystalline structure. The first two types correspond to the distinctly radial and indistinctly radial textures, respectively, and the remaining two to the optically jagged-granular and mosaic-granular textures. The main factors which cause these types involve undoubtedly genetical and possibly environmental effects. A slight difference in the shape of crystal units is ascribed to specific difference and dramatic difference in radial-granular texture is considered as generic importance. These ultrastructures seem to have resulted from intrinsically similar calcification processes; the fundamental structure of crystal elements is similar to each other, but the difference exists in their inclination. This observation indicates that the radial-granular texture has no taxonomic significance in the suprageneric classification.

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INTRODUCTION

It is well known that the cassiduline foraminifera, which evolved into many different forms during the period from Late Cretaceous to Recent, are characterized by its worldwide occurrence. Because of their diversified nature of external and internal test morphology and the wall structure of the group, many taxonomic categories ranging from varieties to families have been proposed by various workers since d'Orbigny (1826).

In the classification scheme of Loeblich and Tappan (1964a, b, 1974), which is essentially based upon wall microstructure (in the sense of Wood, 1949) and toothplate) in the sense of Hofker, 1951a, b, *et seq.*; Nørvang, 1958), this group was divided into two families — Cassidulinidae in the superfamily Cassidulinacea and Islandiellidae in the superfamily Buliminacea —, each of which was considered to have been evolved in their respective phylogenetic lineages by attaining isomorphism.

In spite of those intensive studies, there are much discrepancies as to such problems as specific and generic determinations, taxonomic significance of wall structure, aperture and its modification. At what taxonomic level is it most reasonable to use these wall microstructures for taxonomy? As considered by Loeblich and Tappan (1964a), do the radial and granular wall textures never change from one taxonomic category to the other since they evolved independently from the ancestoral wall type? These problems present the most heated controversies and matters of great urgency to be resolved.

In addition, chaotically entangled nomenclature gives rise to further confusion in foraminiferal systematics. It is often evident that inadequate description and figures would make many foraminiferal taxa practically unrecognizable or undistinguishable, so that the same species is repeatedly described under different specific names. These unnecessary specific name impede understanding of natural relationship of respective species and of the relevance of a given species to specific environments. A well-known species, *Cassidulina subglobosa*, which has been recorded from Japan, has been interpreted in a much wider sense than the original description given by H.B. Brady (1884). Therefore, its paleoecologic, staratigraphic, taxonomic, and systematic interpretations may become difficult.

As recognized by Asano and Nakamura (1937a), species of this group are abundant in marine Cenozoic and Recent deposits in and around the Japanese Islands, where they have characteristic geographic and stratigraphic distributions, although these characteristics have largely been neglected by later workers.

In such a situation, the present investigation attempts to clarify the morphological and structural features which have incompletely been described or misinterpreted, and to formulate a systematic classification of cassiduline foraminifera by using a light microscope and scanning electron microscope (SEM). As far as possible, topotype specimens from Japan were investigated in order to avoid any taxonomic confusion. For this purpose, all the observed morphological characters such as wall microstructure, internal test structure, ontogenetic variation, perforation, lamellarity,

surface ornamentation, aperture and its modification, among others which will be pointed out later, were examined, and their bearing on taxonomy is re-evaluated and incorporated in the present study. Many terms were introduced to these features in order to bring about a better understanding of various criteria. Such information would help to realize a more precise relations among individuals collected from different localities, which are important to establish phylogenetic evolution and to delineate geographic provinces.

ACKNOWLEDGEMENTS

The writer expresses his deep gratitude to Professor Yokichi Takayanagi of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University for his continuous guidance and encouragement during the course of the present study. Deep appreciation is expressed to Associate Professor Kunihiro Ishizaki of the same Institute for advice and critical reading of the manuscript. Gratitude is due to Professors Tamio Kotaka, Nobu Kitamura, and Associate Professor Kei Mori of the same Institute of Tohoku University for their valuable suggestions and encouragement. Sincere thanks are also due to Professor Tsunemasa Saito of the Institute of Earth Sciences, Faculty of Science, Yamagata University for the improvement of the manuscript.

The writer wishes to extend his thanks to Associate Professor Toyosaburo Sakai of the Faculty of General Education, Utsunomiya University for his kind advice on facility of a scanning electron microscope; to Associate Professor Yasumochi Matoba of the Institute of Mining Geology, Mining College, Akita University, for his valuable advice; to Drs. Motoyoshi Oda, Kenshiro Ogasawara, Shiro Hasegawa, and Nobuyuki Honda, all of Tohoku University, for their valuable suggestions and offers of samples; to Associate Professor Nobuaki Niitsuma of the Institute of Earth Sciences, Shizuoka University, for comment; to Dr. Kikuo Watanabe of the Japan Petroleum Exploration Company, Nagaoka, for information on sampling in Niigata Prefecture.

Thanks are also due to Mr. Shohei Otomo of the Tohoku University for his photographic assistance.

COMPARATIVE ANATOMY OF WALL STRUCTURE AND INTERNAL STRUCTURE

1. Introduction

During the last few decades, our knowledge on life-cycle, cytology, ecology and test structure of foraminifera in general greatly advanced. However, many baffling problems still remain to be resolved, and new and complex questions have been put forward for further consideration. The recent trend in classification of calcareous foraminifera has particularly emphasized the importance of mineralogy, microstructure, and formation pattern of secreted tests on the assumption that these features are genetically determined product of living organisms through metabolism (Loeblich and Tappan, 1964a, b; Reiss and Schneiderman, 1969; Reiss, 1971; Tappan, 1976).

Such structural characteristics as crystalline structure, aperture, and surface ornamentations, of which observation can not be made satisfactorily with the inadequate resolution power of an optical microscope, have facilitated by the aid of a scanning electron microscope and transmitted electron microscope.

Attempts to use an electron microscope

to the study of Cassidulinidae have been meager, but a few works along this line of approach are those on the lamellarity of *Cassidulina crassa* by Hansen and Reiss (1972b), crystalline structure of some species by Stapleton (1973), Bellemo (1974a, b) and Conger, Green and Lipps (1977), and apertural structure of nine species by Rodrigues, Hooper and Jones (1980). Most of other previous works were based upon observations using optical microscope.

Important structural features observed in other hyaline foraminifera should be historically reviewed here. About a century ago, Sorby (1879, p. 64) described crystallographic structure of hyaline foraminifera as follows; "their shell is often composed of small prisms of calcite, having their principal axis perpendicular to the surface of the shell .... each cell gives rise to a black cross and coloured rings when seen with polarized light. ....occasionally nothing can be seen but granules without definite optical arrangement." Sollas (1921) elaborated on a minute structure of foraminiferal test. Wood (1949) systematically investigated hundreds of species from many families, following the classification of Cushman (1940), and found three types of wall structure in hyaline foraminifera, namely radial type constructed of perpendicularly arranged crystals to the test surface, granular type consisting of diversely oriented grains showing tiny flecks, and abnormal type made up of a single crystal of calcite (*e.g.*, *Patellina*, *Spirillina*, and *Patellinoides*) and of many elliptical spicules of calcite (*e.g.*, *Carterina spiculotesta*). He also noted the existence of both radially built and granular types in one genus (*e.g.*, *Virgulina*, *Cassidulina*, and *Ehrenbergina*), and considered that the microstructure of the test is a character of taxonomic importance.

Krasheninnikov (1956) further subdivided both the radial and granular structures based on the crystal size and shape: the radial structure comprises a finely radial (*e.g.*, *Cassidulina* sp., composed of 0.5–1.0 μm crystals with pores of 1.0 μm in diameter), coarsely radial (*e.g.*, *Ammonia beccarii*, composed of 2–3 μm crystals with pores of 3–4 μm in diameter), and indistinctly radial (*e. g.*, *Elphidium latusovum*, composed of vermiculated elongate crystals) structure. The granular walls include jagged granular (*e.g.*, *Nonion soldanii*, composed of equal grains of 2–3 μm, commonly 4–6 μm and rarely consisting of minute grains of 1–1.5 μm, and larger grains of 10–12 μm), lamellar granular (*e.g.*, *Cibicides lobatulus*, consisting of much smaller minute grains (0.5–0.7 μm) of equally angled to jagged outlines with distinct three layers), and microgranular (*e.g.*, *Canalifera eichwaldi*, characterized by the appearance of short and thickened crystals) structure. The size of granules ranges from 0.5 to 1.5 μm. He concluded also that the radial-granular texture might have some value for systematic purposes.

The wall structure distinguished by Wood (1949) was regarded to be important to the suprageneric classification by Loeblich and Tappan (1964a). They considered that the radial and granular groups originated independently from the Late Paleozoic Endothyracea (Loeblich and Tappan, 1964b, 1974; Tappan, 1976). However, the validity of these wall structures for establishing suprageneric calssification has been questioned by many workers. For example, *Turrilina brevispira* from the Eocene of Holland and *T. alsatica* from the Oligocene of Denmark, all reported by Hansen (1972a) have a nearly identical external shape and internal structure, although the former has the granular texture and the latter has the radial texture. Therefore, he concluded that the wall structure of *Turrilina* changed from the granular to radial in the

Oligocene, and the radial-granular characters of wall structure should be placed at the specific level only. Towe and Cifelli (1967) clarified the confusion of the usage of these terms, radial and granular, and described various crystallographic structures and their modes of formation. According to them, in the radial texture, nucleation and development of calcite perpendicularly occur along any axis of binary symmetry; that is, the (0001) or basal pinacoid is a plane of growth fixed by epitaxy, whereas in the granular texture, calcite initiates growth perhaps on a hexagonal (1011) face (rhombohedron). These hypothetical crystallographic orientations were collaborated by Hansen (1968) by means of a X-ray diffractometer.

Towe and Cifelli (*op. cit.*) pointed out that a change from radial to granular microstructures could occur by a stereochemical modification in the active organic matrix. Hansen (1970) subsequently recognized optically and ultrastructurally radiate forms such as *Nodosaria letejugata*, *Polymorphina* sp., *Bulimina midwayensis* and *B. marginata*, and defined the crystal units as one or more crystals with identical optical orientation enveloped by a membrane. Bellemo (1974a, b), in the genera *Cibicides* and *Cibicidella*, distinguished two additional wall structures based on the inclination of crystallites to the wall surface. Namely, the intermediate wall type (almost perpendicularly arranged crystallites and obliquely arranged ones in the central part of the wall) and the compound wall type (approximately perpendicularly arranged crystallites in the inner layer and the crystallites parallel to the test surface in the outer layer). He correlated also elongate directions of the crystallites with the optical axis. However, as pointed out by Hansen and Lykke-Andersen (1976), this line awaits confirmation by further study with the application of different methods.

A study of lamellar structure of the test was initiated by Smout (1954) in the Rotaliidae. Subsequently, Reiss (1957) investigated in more detail and distinguished three structural patterns in the lamellar foraminiferids, which were considered to be of taxonomic importance (Reiss, 1958, 1959, 1963a, b, c): a monolamellar, bilamellar and rotaliid pattern. Loeblich and Tappan (1964a, b) followed the Reiss's opinion, and considered that the Cassidulinidae has monolamellid septa. They further stated that the dark lines of median layer separating the inner lining and the outer lamella are composed of a three-dimensional network of organic matter, which may or may not contain mineral grains. These lamellar patterns, particularly bilamellar structure, have been positively supported by many workers in most benthic and planktonic foraminifera.

Hansen and Reiss (1972b) demonstrated by the SEM that six genera considered to have monolamellar structure are composed of the bilamellar structure, and pointed out that all perforate lamellar foraminifera possess a basic bilamellar construction pattern with no taxonomic significance in the Rotaliida. The term pseudotrilamellar was proposed by González-Donoso (1969) for the structure in *Planulina* and *Heterolepa* which are composed of inner lining, outer lamellar, and septal flap. However, the reliability of the primary lamellar character has been repeatedly disputed by Hofker (1964, 1967, 1969, 1971) in use of an optical microscope, particularly in planktonic foraminifera. Towe (1971), based on electron microscopic observations of both living and fossil planktonic forms, pointed out that the lamellar wall construction is variable, sometimes showing a bilamellar structure, often not, and the use of bilamellar structure in higher level taxonomy is not warranted. Conger, Green and Lipps (1977) reported that *Cassidulina* has a monolamellar

test of granular calcite crystals.

From the observation of the primary lamellar structure, the structural modidifications such as toothplate and ornamentations were discussed in detail and divided into many structural portions, particularly in rotaliacean and asterigerinid foraminifera (Hansen and Reiss, 1971, 1972a). According to them, the toothplate is stated to be formed by the inner lining. In nodosariid foraminifera, Grønlund and Hansen (1976) reported four different categories of monolamellar construction pattern. These are ortho-monolamellar, plesio-monolamellar, atelo-monolamellar, and poly-monolamellar forms.

Various terms have been applied to the interesting structure in pore tubules in tangled way: disc-membrane (disque sombre, LeCalvez, 1947); sieve plate (Siebplatte, Jahn, 1953; Wood and Haynes, 1957; Hay, Towe and Wright, 1963; Lynts and Pfister, 1967; Angell, 1967; Hansen, 1972b; Berthold, 1976a); cupule (LeCalvez, *op. cit.*); pore plug (Arnold, 1954); pore diaphragm (Towe, 1971); Pustulae (pustulate chitinoid laminae, Banner and Williams, 1973); capping disc (Sliter, 1974); and pore plate (Hemleben *et al.*, 1977). Thus, investigation of the test microstructure by means of electron microscope seems to be a difficult task in contrast to the limited resolution of a light microscope. Different methods of ultrastructural study may sometimes produce a different result even in the same species.

2. Methods

Specimens were identified and examined for their chamber development at various stages by means of ordinary transmitted light, polarized light, and scanning electron microscopes.

Although most specimens could be cleaned by using the Naphtha method, they were further washed to remove undesirable extraneous matrixes around and within the aperture as well as on the test surface using such standard washing techniques as ultrasonic cleaning, pubbling in H_2O_2, and careful brushing. These

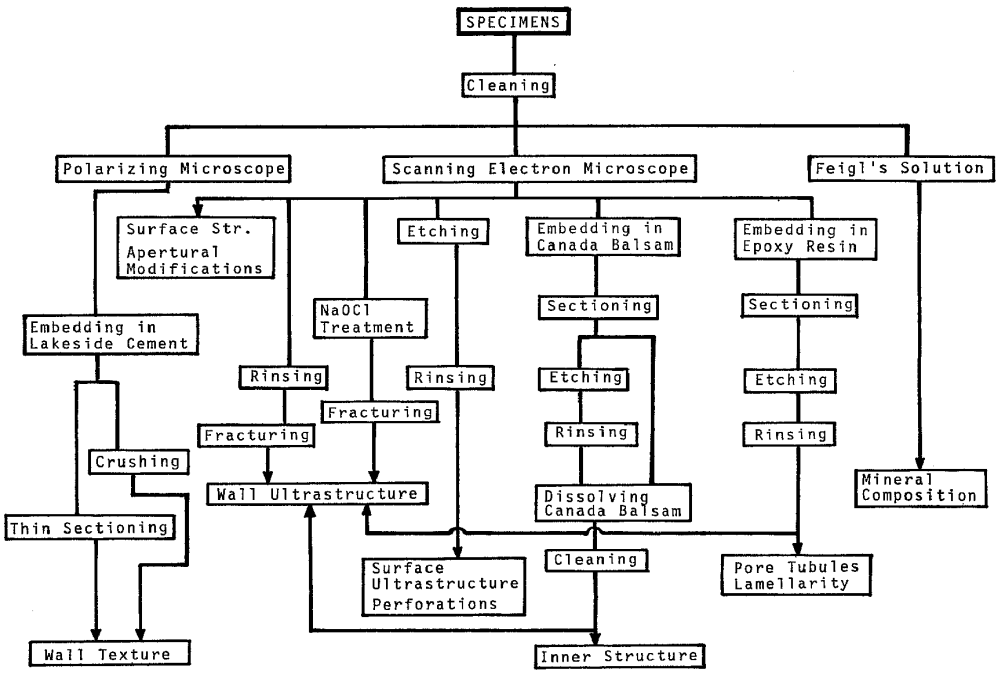


Fig. 1. Flow chart of procedures used in this study.

treatments removed materials hindering observation of structural detail. In order to ensure consistency in structural observation of respective species, the following procedure was used in this study (Fig. 1).

Polarizing microscope: – To make optical distinction of radial hyaline from granular ones and of their optical properties, thin sections and crushed piece of test walls were investigated with a polarizing microscope. The thin sections of test were prepared by embedding the test in horizontal and transversal directions in Lakeside 70 cement on a slide glass and grinding them. The crushed specimens were made on a slide glass using Lakeside 70 cement as a mounting medium. For the observation of non-crushed specimens, complete specimens were placed in immersion oil or sometimes in Canada balsam. Both of the embedding medium can be dissolved by xylene.

In the course of this study, some specimens having a granular texture were examined to determine the optical axis of crystal units using an universal stage. But this attempt gave an unsatisfactory result. Because of the optical limits of resolution under ×400 magnification in the U-stage, each crsytalline unit appears too minute and complicated to confirm optical orientation.

Scanning electron microscope (SEM): Observations of such ultrastructures as surface structure, inner structure, lamellarity, structure of pore tubules, shape of pores, and crystalline structure were made by means of a scanning electron microscope. All the prepared specimens or epoxy disks containing embedded specimens were mounted on a specimen stub by using a piece of double adhesive tape. Sometimes metal conductive paint was partly used. For the observation of fractured wall sections including those etched with a NaOCl solution as well as non-etched ones, specimens were prepared by carefully fracturing them with a fine needle on the specimen stub. For the observation of lamellarity and pore tubules, they were embedded in an epoxy-resin, so that pore linings are depicted based on an artificial mold. The inner structure was studied by preparing specimens with the Canada balsam-Xylene method (Nomura, 1983).

Observed specimens can be removed easily from the specimen stub by reimmersing them in a water droplet and gently teasing them with a fine brush. When it is difficult to remove them, a drop of Aceton is applied. It is therefore possible to use the same specimen repeatedly. For example, specimens examined for the surface structure can also be used for the observation of inner structure, and specimens used for the observation of inner structure can be used in turn for an anatomical study using the Canada balsam-Xylene method.

Embedding: – For the preparation of polished sections, specimens were embedded in an epoxy resin, super low-viscosity embedding media (Polysciences Inc.). A harder resin is obtained by eliminating the D.E.R. 736. The adopted embedding procedure is described by Takayanagi, Niitsuma and Sakai (1968). Namely, the cleaned specimens were placed on a glass slide and glued in a desired orientation with a small amount of a gum tragacanth solution. They were fixed in a short vinyl cylinder (about 1 cm in diameter). The mixed epoxy resin was then poured in to fill the vinyl cylinder. After this, the pre-cured specimens were placed in a vacuum oven to pull air bubbles out from the interior of embedded specimens. About 8 hr. at 76°C is required to cure the resin. When the resin is completely polymerized, the vinyl tube is removed, and the cylindrical plugs are ground and polished.

Grinding and polishing: – For sectioning and half sectioning each specimen, the same grinding procedure was applied. By using a coarse-grained abrasive, No.

400 Carborundum, the surface of specimens was ground on a grinder or on a plate of coarse-frosted glass. They were further ground manually using No. 800 to 2000 Carborundum on a medium- to fine grained frosted glass plate until a desired cross section exposes. When the desired level is reached for the specimens embedded in Lakeside cement or Canada balsam, No. 3000 Carborundum or MgO powder was finally used as a polishing medium. For the specimens embedded in the epoxy resin their surface were polished on a sheet of wet cloth with MgO powder. Ultrasonic cleaning was finally applied to all the prepared specimens in order to remove skeletal debris and polishing media left on the specimens which may obscure morphological details.

Etching: – Before etching, specimens were thoroughly washed with distilled water and fully dried in room temperature. The specimens were etched with a 2.5% solution of phosphate (0.5 M)-buffered glutaraldehyde. The best results were obtained by etching with this solution for 4–15 sec. For studying each crystalline structure, etching time was changed. To etch the uppermost test surface, about 4–7 sec. are required, and for the observation of molded pore-tubules and somewhat deeply etched crystalline components about 10–15 sec. are required. But for the observation of crystalline structure, 4–7 sec. are most suitable. The etched specimens were rinsed several times in distilled water.

The present writer also used a sodium EDTA solution buffered to pH 7.0 by NaOH for the observation of crystalline structure, but this solution appeared unsuitable to analyse crystalline structure in comparison with a glutaraldehyde solution. In order to remove organic matrix from the test walls, another etching was done with a concentrated solution of sodium hypochlorite contain ing 4% active chlorine. For this treatment, about 5–20 days are required to completely resolve the organic materials. During this etching, the precipitation of NaOCl occurs on the test surface for a long time etching, but it easily resolves in distilled water. Therefore, the etched specimens must be washed many times in distilled water in this treatment.

Mineralogical determination: – The specimens etched with a NaOCl solution are immersed in Feigl's solution. The Feigl's solution preferentially stains aragonite relative to calcite. But this reaction rate, as is well known, varies with temperature. Therefore, the present writer beforehand tested reaction time by using known aragonite and known calcite. In this study, X-ray analysis was not made, because of insufficient number of specimens.

All the specimens examined with the scanning electron microscope were coated with gold (thickness approximately 200 Å) in high vacuum. The scanning electron micrographs on accompanying plates were taken by JEOL-JSM-U3 scanning electron microscope with an acceleration of 15–25 KV. All the examined materials are deposited in the Institute of Geology and Paleontology, Tohoku University, Sendai (Abbreviation IGPS).

3. Wall microstructure

3–1. *Wall composition*

Seventy-four species of the Japanese Cassidulinidae bear wholly calcite test as determined by Feigl's solution. Blackmon and Todd (1959) and Todd and Blackmon (1956) suggested that the mineralogic nature of tests is a generic characteristic and related at the family level, and environment appears to have no influence on the presence of either calcite or aragonite, and the two minerals do not occur together in foraminifera.

3–2. *Color in reflected light*

In both fossil and Recent tests of the Cassidulinidae, three different appearances

were recognized in this study; opaque, semiopaque to translucent, and transparent in dry conditions.

In the most well-preserved state, it is noted that each wall appearance is a result of their particular wall structure. That is, the transparent wall is mostly characterized by an optically distinctly radial texture in such species as *Islandiella norcrossi*, *I. helenae*, *I. yabei*, and *Takayanagia delicata*, but also seen in some thin-walled species having the jagged as well as mosaic-granular textures. The translucent wall occurs in a larger part of the Cassidulinidae, and is particularly represented by the jagged- and mosaic-granular textures. However, the distinctly radial texture, thickly laminated, shows this feature. The opaque wall may have also been referred by various authors as a matted or porcellaneous appearance similar to that of miliolids. This feature is mostly represented by the indistinctly radial texture in such species as *Islandiella wakasaensis*, *I. japonica* and *I. setanaensis*, and the jagged- and mosaic-granular textures which are thickly laminated as shown in the early portion of *Burseolina pacifica*, *Globocassidulina subglobosa*, *Lernella inflata*, *etc.*

These features have been recognized as an attribution in large part to their internal structure (Wood, 1949; Hofker, 1951b, 1956a, b; Glaessner, 1954; Reiss, 1958). As already pointed out by Reiss (1958), both "hyaline" and "opaque" in Hofker's sense (Hofker, 1951b, 1956a, b, and in his several papers) have been used to represent structural distinctions.

Wood (1949) drew much attention to the hyaline and porcellaneous appearance in hyaline foraminifera, and attributed these to the internal clashes of reflected light from the interior of test. According to him, that is controlled by the following: the relationship of the pore size to the wall thickness; increase in thickness of the wall; presence of internal chambers; and ornamentation or cancellation of the test surface. However, changes from transparent to opaque are also well known to be brought about by such post-mortem effects as the decay of protective outer membrane and the subsequent etching of calcium carbonate (Reiss, 1958; Buzas, 1966; Murray, 1967; Murray and Wright, 1970; Banner and Williams, 1973). Murray's experiment (1967) using a water with lowered pH by bubbling carbon dioxide clearly demonstrated these color changes in the hyaline tests.

In the present study, the present writer observed a color change from the transparent and translucent walls to the opaque wall by etching the tests with a NaOCl solution which was originally used to remove organic material. Moreover, the opaque tests occasionally associate with the transparent or translucent tests in a given species and/or in the same sample. The opaque tests possess brittle walls compared with the non-opaque ones in spite of similar surface structure. This feature is quite similar to that of the specimens treated with a NaOCl solution. Therefore, the content of organic material in the wall, possibly distributed in the intercrystalline and interlamellar areas, is considered to play another important role as to the opaqueness of the test.

3–3. *Polarizing light microscopy*

As stressed by Towe and Cifelli (1967), the term radial and granular should be used in reference to the optical phenomena in polarized light, because the radial-granular concept was originally described by Wood (1949) from his optical crystallographic observations in polarized light. He stated as follows; as to the radial wall, "a black cross with concentric rings of colour closely mimicking a typical (negative) uniaxial interference figure, ... the test built of crystals of calcite with their *c*-axes normal to the spherical surface," and as to the

granular wall, "a multidue of tiny flecks of colour, ... The granules are equidimensional and sutured together." The distinction between the two is only made in this way on the basis of extinction characteristics in polarized light, suggesting the connotation of the wall structure.

The term *structure* has been applied to these optical phenomena. Furthermore it is also used in the morphologic sense of crystalline elements. As demonstrated by Towe and Cifelli (*op. cit.*), however, similar optical characteristics can be produced by different crystalline morphologies and *vice versa*. It is clear, therefore, that the optical structures within the limits of optical resolution are, in fact, recognized as apparent feature caused by actual crystalline structures. To avoid the confusion with respect to the term structure, another term *texture* is applied herein, following Glaessner (1963) and Belford (1966) to express the optical phenomena on behalf of the crystalline morphologies observed by the electron microscope.

The radial and granular textures are already known in the Cassidulinidae (Wood, 1949). On detailed examinations of these textures in the Japanese Cassidulinidae, the radial texture is divided into two types, distinctly radial and indistinctly radial textures, based upon a difference of extinction patterns. Based on the shape of sutured units of optical granules, the granular texture is also divided into two types, jagged-granular and mosaic-granular textures (Table 1).

The distinctly radial texture (Pl. 3, figs. 1, 2) is recognized as the representatives of radial texture. It shows under cross nicols the typical black cross like an interference figure of uniaxial crystals in crushed specimens and concentric color rings in the concave and convex chambers. Extinguished portions are permanent and uniform (Pl. 3, fig. 2). But in some species having coarsely perforated and thickly calcified walls the black cross is ambiguously defined on the ground whether or not the optical units around the pores are extinguished (Pl. 3, fig. 1). These forms, when viewed in thin section, show undulatory extinction caused by numerous tiny pore tubules, giving rise to a fibrous texture. The fibrous appearance of wall is safely ascribed to the optical superimposition of the pores within a given wall thickness as indicated by Towe and Cifelli (1967) and Pessagno and Miyano (1968). It is noticeable that some species having a bundle-shaped crystalline structure, which will be described in other section, show an inconsistent feature depending on their wall thickness. Such thicker-shelled forms as *Islandiella japonica* and *I. setanaensis* may produce a heterogeneous extinction pattern. Thus, it is important to point out that a similar optical appearance observed on the walls of different crystalline structure is affected by the thickness of the wall. Intrinsically, at least in radial texture, the optical phenomena do not indicate true crystalline forms.

In any case, it is clear that the wall showing a cross extinction has the optic axis (*c*-axis) almost perpendicular to the test surface (Wood, 1949; Wood, Haynes and Adams, 1963; Wood, 1963; Hay, Towe and Wright, 1963; Towe and Cifelli, 1967; Hansen, 1968, *etc.*). Three genera, *Islandiella*, *Takayanagia* and *Cassidulinoides* possess this texture.

The indistinctly radial texture (Pl. 3, fig. 3) was first observed by Krashenninikov (1956) in *Elphidium latusovum*. Later, Towe and Cifelli (*op. cit.*) clarified reasonably this texture in *Cibicides refulgens* which is still in confusion (*e.g.*, Wood, 1949; Wood and Haynes, 1957; Belford, 1966). Feyling-Hanssen and Buzas (1976) also pointed out that the *Cassidulina* has this texture.

This texture is characterized by its heterogeneous apperance without a black

Table 1. Classification of wall structure under optical microscope.

Wood (1949)	Krasheninnikov (1956)	Towe and Cifelli (1967)	Feyling-Hanssen and Buzas (1976)	Nomura (This paper)
hyaline tests			Cassidulinidae	
radial structure	finely radial str. coarsely radial str. indistinctly radial str.	radial str. indistinctly radial str.	radial str. indistinctly radial str.	distinctly radial texture indistinctly radial texture
granular structure	jagged granular str. microgranular str. three layered-granular str.	finely mosaic granular str. coarsely mosaic granular str.	granular str.	jagged-granular texture mosaic-granular texture

cross in polarized light. The extinction is concentrated in the center of crushed wall, though other extinctions are irregularly distributed. This texture results from the complexed branching crystal elements due to the bundle-shaped crystalline structure (Pl. 4, fig. 2). In such a case, the crystal elements branched out may act to deflect rays of polarized light before they reach analyzer. These subtle differences in preferred orientation of the *c*-axis may manifest irregular extinctions. The *c*-axis is inclined at about 7° to 20° from the normal. This texture is found only in *Islandiella*, most typically in *I. wakasaensis*.

The jagged-granular texture (Pl. 3, fig. 5) represents the majority of species of the Cassidulinidae. As described by Wood (1949) this texture shows minutely granulated sutured units of a uniform yellow polarization color. But paying much attention to the sutured units, they are conspicuously irregular-shaped, apparently ranging from 1.2 to 3.4 μm in size. The term jagged-granular is applied in this paper to apparent irregularities of the sutured units, which may be identical with that of Krasheninnikov (1956), who recognized it in *Nonion soldani* (d'Orbigny), and both coarsely and finely mosaic granulars of Towe and Cifelli (1967) in *Nonion labradoricum* (Dawson), *Chilostomella ovoidea* (Reuss) and *Pullenia quinqueloba* (Reuss).

It is pointed out that the *c*-axes of the respective sutured units are by no means normal to the test surface, but inclined at some angle as mentioned in the following paragraphs.

At low magnification (*e.g.*, about × 100), these sutured units do not show light extinction. But at higher magnification (*e.g.*, × 400) they appear to be very minutely extinguished four times in a revolution. This phenomenon at low magnification may be caused by countervailing polarized light. The jagged feature in polarized light results from the intricate crystalline structure (Pl. 5, figs. 2, 4; Pl. 6, fig. 2), and is furthermore strengthened by the subsequent lamellar superposition. Seven genera *Paracassidulina*, *Globocassidulina*, *Evolvocassidulina*, *Burseolina*, *Ehrenbergina*, *Cassidulina* and *Lernella* possess this texture.

The mosaic-granular texture (Pl. 3, fig. 4) is closely allied to the jagged-granular texture, but differentiated from the latter in having larger sutured units and in the absence of strongly jagged feature. The sutured units, whose array is more conspicuously extinguished in a normal manner, show the uniform pattern apparently ranging from 3.8 to 5.7 μm in size. The smaller units are restricted to *Cassidulina norvangi* and larger ones are only found in the genus *Hastilina*.

Table 1 compares various terms given by Wood (1949), Krasheninnikov (1956), Towe and Cifelli (1967) in hyaline foraminifera except for single crystal forms, and by Feyling-Hanssen and Buzas (1976) in the list of some species of Cassidulinidae, and the present writer's observation.

3–4. *Wall microstructures*

Crystal growth so far as studied is intimately associated with organic matrix

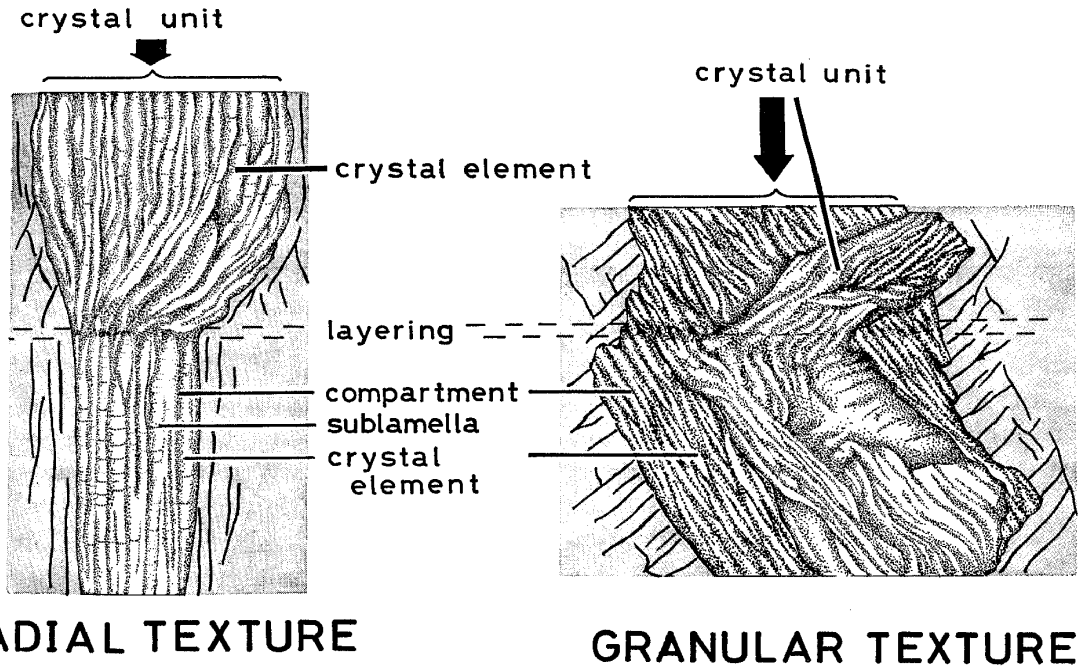


Fig. 2. Crystalline structure of radial and granular textures based on electron micrographs.

which surrounds the crystals of calcium carbonate. Although the morphology of the organic matrix has been poorly understood in foraminifera, any biomineralization theory hitherto presented takes account of the organic matrix, which acts as a template and/or envelop, and is to be formed contemporaneous with calcification. In the recognition of various wall structures, therefore, the *crystal elements*, as called here, are completely enveloped by the organic matrix, which should be considered to be the most basic unit of the calcified tissue.

In this study, the following four crystalline structures are distinguished in the Cassidulinidae based upon the shape, mode of arrangement, and structure of aggregates of crystal elements: (I) fibrous, (II) bundle-shaped, (III) intricate, and (IV) clumpy. The former two are recognized as an optically distinctly or indistinctly radial texture, and the latter two are as optically jagged- or mosaic-granular texture. As shown in Fig. 2, the crystal elements gather to form larger units, which are called *crystal units* as defined by Hansen (1970).

Banner and Williams (1973), and Conger, Green and Lipps (1976) found calcitic layers of *Ammonia* and certain foraminifera in which numerous thin lamellae are deposited before a thicker layer was formed. A similar structure is also found in the Cassidulinidae, particularly the bundle-shaped crystalline structure; many thin lamellae are different from the ordinary organic membranes formed in every instar, and are not continuous all over one calcitic layer. These numerous lamellae appear to be a narrow constriction of the crystal elements, although it is not ascertained in this study as to whether or not they are composed of organic matrix.

Each crystal element consists mostly of a large number of microcrystals having the same crystallographic orientation (Pl. 4, fig. 3), thereby it shows sometimes stacks of tabular calcite crystals with euhedral cleavages (Pl. 3, fig. 6). When every crystal element is arranged in quite the same with one another or in a strictly parallel arrangement with the adjoining crystal elements, larger euhedral crystals are formed. The crystal

units are different from the crystal elements, because the crystal units are composed of many crystal elements, whose strongly distorted or branched parts are regarded as having a different crystallographic orientation.

(I) Fibrous crystalline structure (Fig. 3, (I)): This structure is defined by fine needle-shaped crystal elements with a distinct preferred orientation perpendicular to the test surface. Every crystal element of about 0.1 to 0.2 μm in diameter is uniform without any branching, and is separated from one another by the intracrystal organic matrix (Pl. 4, fig. 1; Pl. 5, fig. 1). The crystal units are apparently not formed in this structure. These crystal elements are terminated by very thin outer and inner veneers of calcitic crystallites. Figure 3(I) shows a schematic black-diagram of this structure. Various features (A, B, C, D) of the upper test surface after etching reveal continuous structural patterns from the outer veneer to the fibrous structure. When the uppermost microcrystallites (A) are etched, the veneer appears to be irregularly sutured and arranged in an interlocking fashion (B) in the sense of Towe and Cifelli (1967) (Pl. 7, fig. 12; Pl. 8, fig. 4). In detailed examinations, the sutured veneer appears to be a jig-saw puzzle (Pl. 8, fig. 4). Constricted pores are usually open at the sutured boundaries. Further etching reveals that the sutured nature becomes more complex, and is heavily interfingered (C) (Pl. 7, fig. 9; Pl. 8, fig. 5). The width of each finger ranges generally from 0.15 to 0.20 μm, and almost equal to that of the crystal element. Removing the veneer, a truncated fibrous structure appears (Pl. 7, fig. 10; Pl. 8, fig. 6). Electron micrographs of the final chamber wall of *Islandiella norcrossi* (Pl. 4, fig. 1) clearly demonstrate the same structure. As mentioned above, the crystal units are not found in this structure, although the jig-saw-puzzle-like sutured veneer links up with a certain number of crystal elements. Therefore, each sutured unit of the veneer is interpreted to correspond to the crystal units in cross section. The reason why the crystal units are indistinct may be attributed to the close similarities of respective crystal elements and intra- and inter-crystal organic matrices.

The crystal elements between the primary calcitic lamella and the secondary calcitic lamella do not change their structural features. As already mentioned, the organic membranes separating respective calcitic lamellae are usually indistinct in this structure. The crystal elements in this membrane appear to be very slightly constricted (about 0.1 μm). Pore tubules in the chamber wall are usually parallel with the crystal elements and are tightly surrounded by them. Around the sutured regions, the pore tubules run obliquely in relation to the crystal elements and are surrounded by very thin other crystal elements.

This structure is observable in some species of several different genera — *Islandiella norcrossi*, *I. helenae*, *Takayanagia delicata*, and *Cassidulinoides subcylindricus*.

(II) Bundle-shaped crystalline structure (Fig. 3, (II)): This structure is defined by curved crystal elements and bundle-shaped crystal units (Pl. 4, fig. 2; Pl. 6, fig. 1). Respective crystal elements vary in diameter from 0.08 to 0.40 μm and present an irregular outline (Pl. 4, fig. 4). It is also noticeable that the crystal units are divided into many branches (Pl. 3, fig. 7) and seemingly fused with the neighboring crystal elements. The crystal units wedge out inward and spread out toward the outer test surface. Most aggregates are initiated at the base of the calcitic lamella showing a pointed structure, but there are many units diverged from other different units in a calcitic lamella. Based on the degree of divergence of the

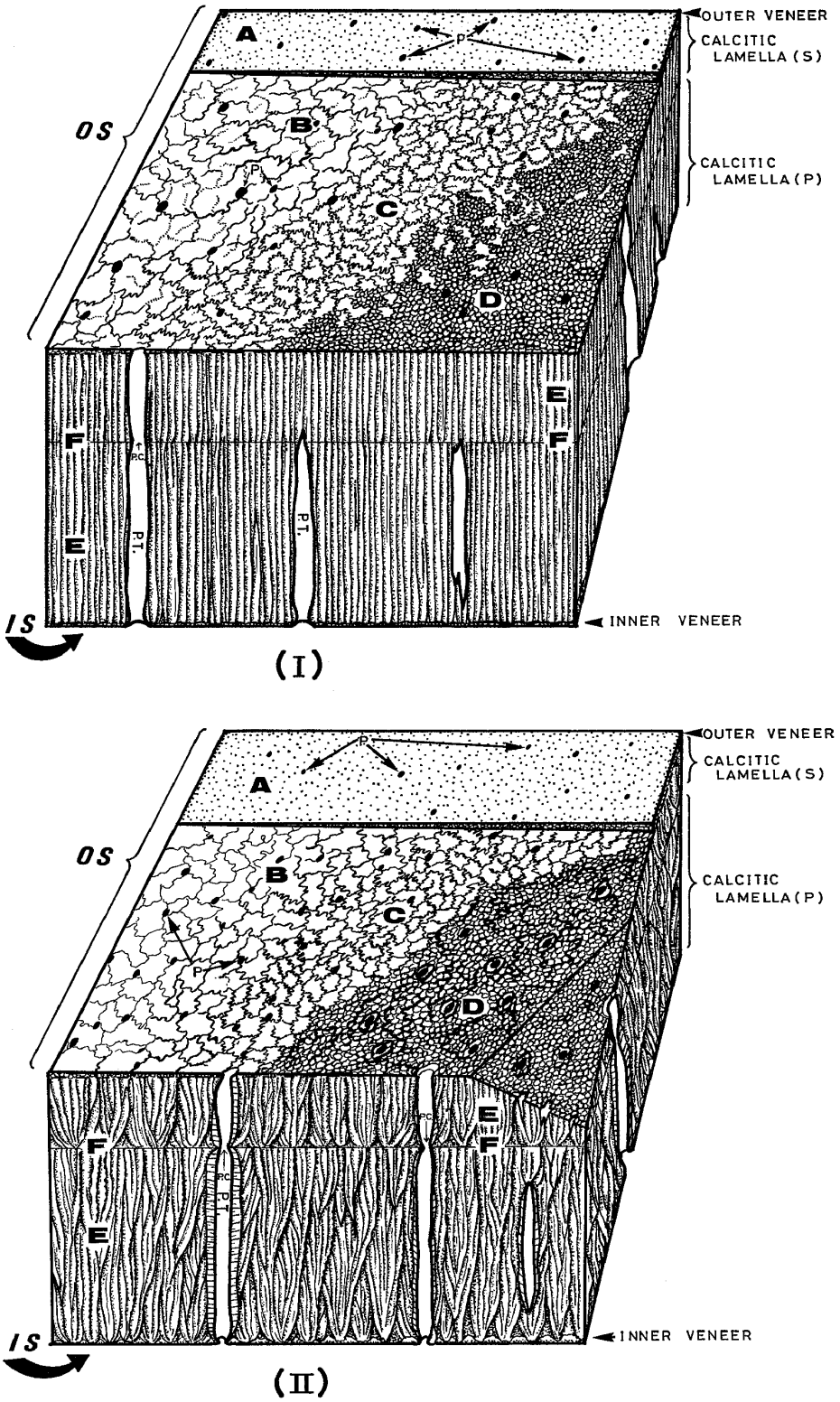
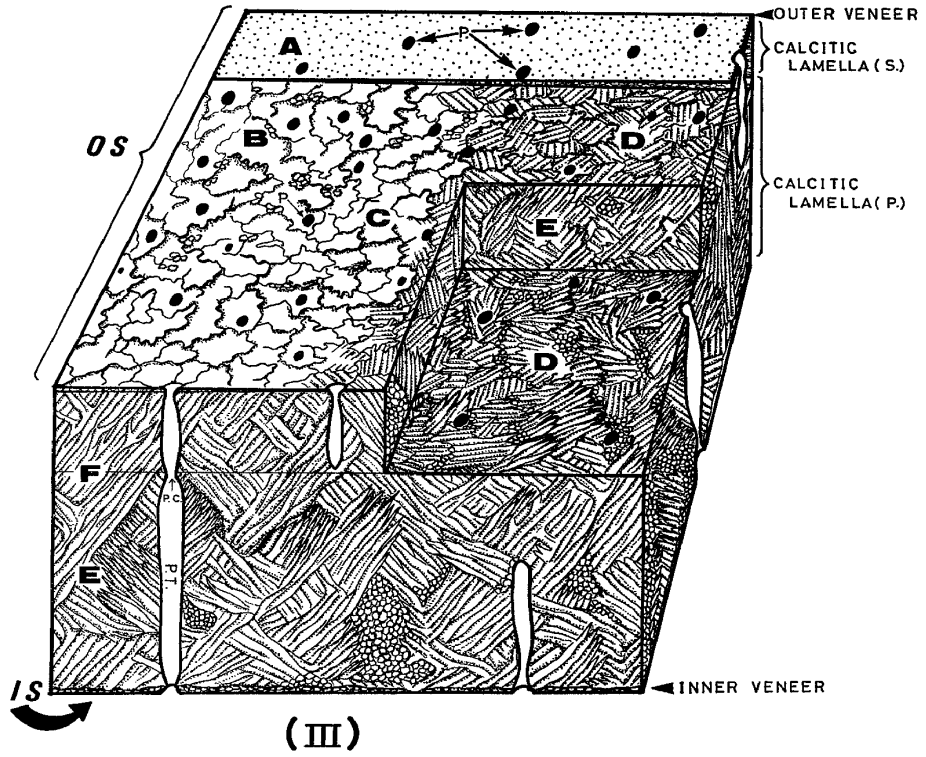
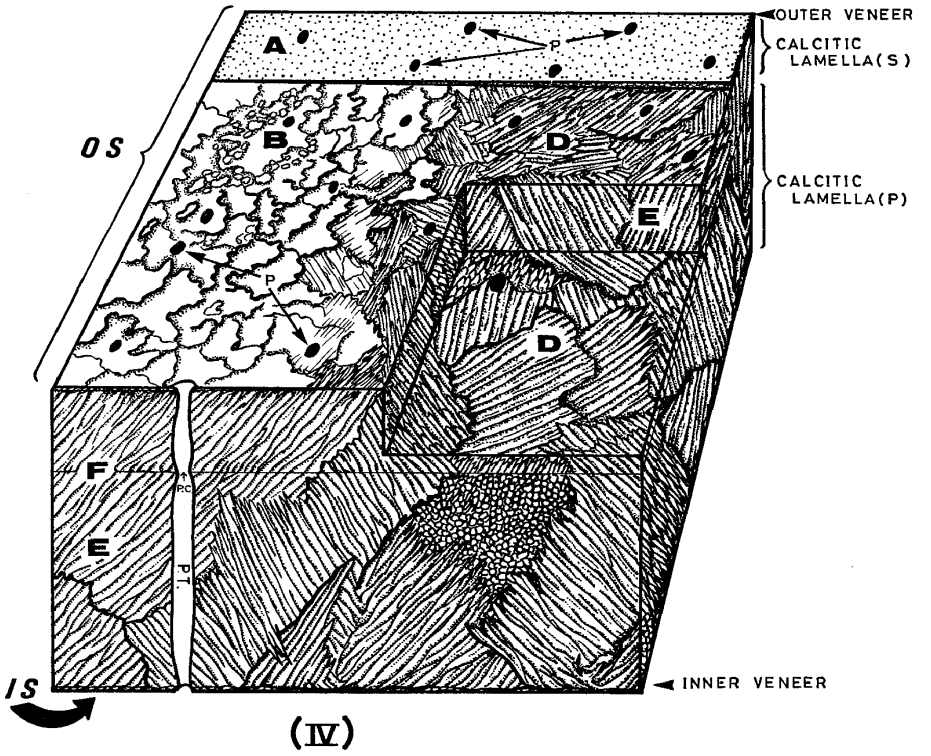


Fig. 3. Block diagrams showing the wall structure of penultimate chamber. (I)=fibrous crystalline structure, (II)=bundle-shaped crystalline structure, (III)=intricate crystalline structure, (IV)=clumpy crystalline structure. B, C and D on the surface indicate figurative expressions of outer veneer and calcitic lamella on different degrees of etching. A=featureless



(III)



(IV)

microgranules of the outermost veneer, B and C=crystal units of outer veneer, D and E= crystal units and crystal elements of crystalline structure, F=organic layer bounded by the primary calcitic lamella (P) and the secondary calcitic lamella (S). OS=outer test surface, IS=inner test surface, pt=pore tubules, P.C.=pore constriction, p=pores.

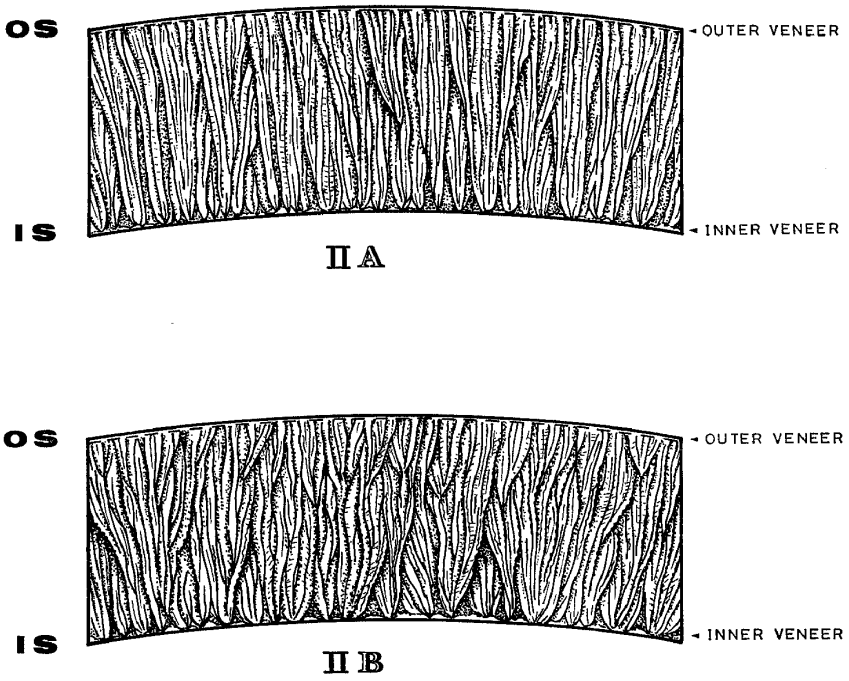


Fig. 4. Cross sections of bundle-shaped crystalline structure, showing a variety of diverging angles of crystal units and elements.

crystal units, this structure may be further divided into subtypes (Fig. 4). The first subtype shows little divergence and little branching as seen in *Islandiella sublimbata* (Pl. 4, fig. 2). Their diverging angles are 10°–20°. Another subtype is characterized by a more remarkable divergence and branching as seen in *Islandiella wakasaensis*. Their diverging angles are 27°. The crystal elements are built of tabular microcrystals (Pl. 3, fig. 6) as first clearly demonstrated by Bellemo (1974a, b) in the radial-walled species. The thickness of each microcrystal is about 0.05–0.15 μm. The different cleavage pattern of microcrystals in respective crystal elements indicates that every element consists of several microcrystals in a slightly different crystallographic orientation from one another.

The structure of the veneer is quite identical with that found in the fibrous structure. A, B and C on the outer test surface respectively indicate variations of crystal units resulted from different etching times. Morphological granular or truncated features appear when the outer veneer is removed (Pl. 10, fig. 2). Each grain is nothing but the apex of the crystal elements. The sutured units of outer veneer almost correspond to the crystal units. The inner veneer, which is mostly composed of microcrystallites, does not conspicuously show these sutured units. But slightly incised grooves are visible in the interpore regions (Pl. 10, fig. 3).

The secondary organic membranes (F) are also indistinct in this structure. The crystal units in the secondary calcitic lamella are diverged newly from the surface of the preceding calcitic lamella so far as externally viewed, and every crystal element in the primary and secondary calcitic lamellae is linked with one another, forming a slight constriction (Pl. 4, fig. 2). It seems that the newly formed crystal elements are built on the preceding elements. The pore tubules are compactly surrounded by relatively larger crystalline units in comparison with those of the fibrous

structure.

It is noteworthy that the pore tubules are not always alligned parallel to the crystal elements. As shown in Plate 6, fig. 1, the crystal elements are oblique to the tubules. Therefore, the crystal elements surrounding the tubules produce quite different crystallographic orientations. Observations in a transmitted light suggest that the fibrous texture also owes to these effects. The same structural feature was illustrated in *Lenticulina calcar* (Towe and Cifelli, 1967, p. 91, fig. 1). This structure is observed in most of the species which have a rather thick wall.

(III) Intricate crystalline structure (Fig. 3, (III)): This structure is characterized by strongly branching and inter-digitating crystal elements. The crystal units are built of bundle of crystal elements. With such a complex form, it is difficult to estimate the total size of the units. The width of the unit may be approximately 2.5 μm, and the crystal element appears to be about 0.2 μm wide. These dimensions are almost equal to those of the aforementioned two structures.

The branching angle of the crystal elements varies from place to place. It ranges about 60°–125° in the chamber wall; usually 85°–105°. The angle between the test surface and the preferred orientation of crystal elements ranges from 25° to 75°; mostly 45°–55°. This may indicate that the optical *c*-axis is not randomly oriented as pointed out by Towe and Cifelli (1967).

The structure of the outer veneer is similar to those of other structural features, but on a slightly etched surface (B, C, in Fig. 3 (III)), the sutured patterns appear to have more irregular inter-digitations associated with further minutely separated units (Pl. 12, fig. 8; Pl. 15, fig. 4; Pl. 21, fig. 5; Pl. 25, fig. 5). A similar feature is also observable in an electron micrograph of *Chilostomella ovoidea* illustrated by Towe and Cifelli (1967, pl. 96, fig. 3). The outermost surface of the calcitic lamella is composed of numerous intricate crystal units, showing an amoeboid array. The optically granular texture is characterized by this amoeboid array. Towe and Cifelli (*op. cit.*) described that the structure within a sutured boundary is uniform and may be a single crystal, although this is not true morphologically. As shown in electron micrographs, each amoeboid array is identical with the crystal unit viewed in cross section and is composed of many crystal elements. The same structural pattern occurs in the inner test surface when the inner veneer is etched (Pl. 20, fig. 7), but the crystal elements in each unit tend to converge and are almost parallel with the inner test surface.

The structure between the primary and secondary calcitic lamellae indicates that the crystal units correspond to the outcrop of inner surface, and are arranged in similar orientations. The direction of the crystal element in the subsequent calcitic lamellae is usually conformable with the orientation of the preceding crystal elements forming further branching units. The pore tubules run oblique to the adjacent crystal units. But another crystal elements, as observed in the fibrous and the bundle-shaped crytalline structures, are absent. The tubules are only surrounded by the organic lining (Pl. 5, fig. 5).

This structure is most common in the Cassidulinidae. The following genera are characterized by this structure; *Paracassidulina, Globocassidulina, Evolvocassidulina, Burseolina, Ehrenbergina, Lernella* and some *of Cassidulina.*

(IV) Clumpy crystalline structure (Fig. 3 (IV)): This structure is closely allied to the intricate crystalline structure. But compared with the latter structure, the crystal units and its elements are not intricate, so that boundaries among the crystal units are well defined. Further-

more, this structure is characterized by larger units (about 4 μm in average width). The crystal elements are identical with those of the structures described above, but are not so frequently branched.

The preferred orientation of the crystal elements suggests that the optical axis may be oriented to the test surface at an angle of between 40° and 50° as in the case of the intricate crystalline structure.

The structure of the outer veneer is also identical with other structures. The amoeboid array on the outer calcitic lamella are larger and well defined (Pl. 24, fig. 2). They are slightly overlapping at the periphery, and appear as in Plate 1, fig. 8. The pores on the test surface usually occur within the amoeboid array of the crystal units.

This structure is recognized in *Cassidulina norvangi* and most species of *Hastilina*.

Somewhat different crystalline structures were found on the apertural ridges, tip of the primary and secondary tongues, lips, pseudolips, keels and other inflated ornamentations. The apertural ridges recognized as a thicker feature show more strongly branched crystal elements (Pl. 4, fig. 7). The bundle-shaped crystal unit in the primary and secondary tongues displays a feature of the intricate crystalline structure (Pl. 4, fig. 6).

3–5. *Microtopography of inner and outer test surfaces*

In reflected light, best-preserved test surface shows three different features; the first appears a glassy surface with flashing reflection, the second is a rugged or pitted appearance with diffused reflection, and the third appears a rough or bumpy surface with dim reflection. These features on the test surface are apparently influenced by the ornamentations and shape of pore opening. Thus, the surface with very small pores shows the first type, the surface with coarse pores (*e.g.*, *Evolvocassidulina brevis*) or coarse ornamentations (*e.g.*, *Globocassidulina decorata*) represents the second type, and the papillated surface (*e.g.*, *Globocassidulina mucronata* and *G. undata*) does the third type.

When these test surfaces are observed with scanning electron microscope at higher magnification, a microgranulated surface composed of myriad crystallites shows up. These microcrystalline array is safely assigned to the *veneer* of Towe and Cifelli (1967). Towe and Cifelli noted that the veneer of *Ammonia beccarii* is variable and ranges from a very fine morphologic array to a surface consisting of well-developed rhombs; the veneer of the Cassidulinidae is the former type.

The veneer on a polished surface is characterized by compactly inter-digitated crystallites (Pl. 14, figs. 3, 7; Pl. 16, figs. 4, 10; Pl. 17, fig. 12; Pl. 18, fig. 12; Pl. 22, fig. 8; Pl. 25, fig. 2). The crystallites give only a beaded appearance and range from 0.1 to 0.4 μm in diameter; 0.2 μm in average. According to a study of *Rosalina floridana* by Angell (1979), the beaded surface is formed in the last phase of calcification, and is further covered by a featureless calcitic coating. Although in living forms of the Cassidulinidae, this featureless calcitic coating may probably be deposited on the crystallites, it is very difficult to detect in fossil tests. The veneer on the papillated surface shows somewhat larger and irregular-shaped crystallites with microrelief (Pl. 13, figs. 1, 2). The diameter of respective crystallites is not well defined by ranges from 0.1 to 0.6 μm. They show heterogeneous morphology. On the final chamber wall of *Globocassidulina mucronata* and *G. undata*, respective crystallites are large-sized beads (Pl. 13, figs. 1, 2). The crystallites on the lumps are somewhat smaller than those in the inter-lumps regions. The dimly reflected surface in reflected light may be ascribed to these hetrogeneous

microrelieves in addition to numerous lumps.

The veneered nature of the test is not always restricted to the outermost test surface, but is usually visible on the innermost test surface, as a feature of sandwich structure. So far as the morphology of the crystallites on the outer- and inner-most test surfaces is compared, they are quite the same. The origin of the veneer is unknown. Although, as pointed out by Towe and Cifelli (1967) and Sliter (1974), it may reflect chemical differences between the outer membrane and the inner organic matrix. The *outer veneer* is thus applied to the outermost test surface, and in turn the *inner veneer* is to the innermost test surface. The thickness of the outer and inner veneers in the same chamber wall is almost equal, and attains only about 0.3 to 0.5 μm of microcrystalline size, but the inner veneer on the earlier formed chamber becomes thicker.

It is noteworthy that in some species having much smaller pores but not having larger rounded ones, the outer veneer covers pore opening in a curious way. In this case, the pore openings are nearly closed up by the outer veneer, and the so-called blind pores are formed (Pl. 25, fig. 2). However, the inner veneer does not cover the pore opening. These external shapes of pores formed by these outer and inner veneers will be described in the section of perforation.

The calcite crust on the external wall of some planktonic foraminifera differs strikingly from those of benthic hyaline species in the appearance of shell structure (Bé and Ericson, 1963; Bé and Lott, 1964, and others). However, the outer veneer of some benthic species — *Ammonia* and *Bolivinita* — is also considered to be analogous (except in scale) to that of planktonic species (Banner and Williams, 1973; Stapleton, 1973; Scott, 1978b). Therefore, these authors referred the veneer to the term *crust* or *veneer crust*. As envisaged previously, the calcite crust deposition occurs at the terminal phase of the life history of individuals when individuals descend to deeper water habitats (probably greater than 350–500 m) and when the calcite crust is no longer covered with successive growth lamellae (Bé and Ericson, *op. cit.*; Bé and Lott, *op. cit.*; Bé *et al.*, 1966; Takayanagi *et al.*, 1968; Horibe *et al.*, 1968; Bé and Hemleben, 1970). Moreover, the calcite crust is characterized by large and euhedral calcite crystals on the wall surface in section. Takayanagi *et al.* (*op. cit.*) stated that it is to be about 10 μm to 30 μm in length, and 1 μm to 6 μm in width.

The outer veneer of benthic foraminifera, however, does not show these features and may suggest that the calcite crust in planktonic species is basically different in mechanisms from the veneer consisting of microgranulated crystallites. The term *crust* should not be applied to these external features of benthic species. Stapleton (1973) suggested that the secondary calcite crust (=veneer of the present writer) tends to increase with depth in *Bolivina argentea*, and noted four stages in the development of encrustation. Namely, the first stage is an inception, appearing as a thin layer of very small calcite crystals, the second is the development of zigzag groove pattern, the third is the development of a relatively high relief, and the final is the development of a sinuous groove pattern. However, the writer did not observe the last three stages in the Cassidulinidae; but if they are present, they should be rather similar to the crystalline configuration underlying the outer veneer (see Fig. 3).

Scott (1978b) recognized two styles of the secondary encrustation in fossil *Bolivinita* from New Zealand and Car Nicobar. One is a dome formation, and the other is veneer encrustation. The latter conforms with the observation made

in this study, and the former resembles the outer veneer of a papillate surface (Pl. 13, figs. 1, 3, 4). Contrary to the Scott's suggestion that the dome-like structure may be the accumulation of veneer-type crust, the present writer considers that this structure itself is formed by a local increment of the crystal units during a calcification episode.

As observed by Sliter (1974), the outer veneer is inseparably linked with the calcitic lamella and the subsequent one in the *Bolivina* and *Coryphostoma*. In this point of view, the crystallites of the outer veneer may be recognized as seed crystals of epitaxy in the subsequent calcification phase.

3–6. *Summary of the relationships between optical and electron microscopy*

As illustrated in Fig. 5, the textures observed on crushed specimens in polarized light correspond well to the structure observed in etched sections using SEM.

The optically distinctly radial texture can be referred to as the fibrous crystalline structure having non-branching crystal elements. Forms with bundle-shaped crystalline structure, having exceptionally thinner walls, show an optically distinctly radial texture. This may be attributed to the degree of reflections and refractions of polarized light in a given wall thickness.

The optically indistinctly radial texture shows a bundle-shaped crystalline structure without any exception. This is due to each crystal unit or element with an intrinsically different crystallographic orientation.

The optically jagged-granular texture corresponds to the intricate crystalline structure. The crystal units apparently correspond to the amoeboid granules at the optical level, but their orientations and attitudes vary from units to units. Therefore it is very difficult to decipher the crystal units at the resolution level of optical microscope.

The optically mosaic-granular texture is identical with the clumpy crystalline structure. The clumpy crystalline structure is formed by aggregates having crystal elements not so strongly branching and is characterized by relatively larger crystal units. Consequently, the minute granules within the mosaic units which give polarized light extinction in stage rotation appear almost equal to the crystal units.

The fibrous structure is not identical with the structure recognized as a radial wall structure at the optical level by many workers (Reiss, 1963c). The term fibrous used in this study is defined strictly as the feature of crystal elements. The fibrous appearance in optical microscopy on thin sections is nothing but the superimposition of pores and/or different crystalline elements surrounding them.

4. Lamellar structure

A lamellar pattern and layering of the final chamber wall as well as the septal wall in the Cassidulinidae have been regarded as monolamellar (monolamellid septa of Loeblich and Tappan, 1964a), although later workers demonstrated by means of electron microscope that perforate lemellar foraminifera including the Cassidulinidae possess a basic bilamellar construction pattern (Reiss and Schneidermann, 1969; Hansen and Reiss, 1971; Hansen and Reiss, 1972b, *etc.*). The monolamellar appearance has been attributed to the facts that the so-called black layer of median organic layer is beyond the resolution power of optical microscope, and to different preparational techniques for electron microscopy (Hansen and Reiss, *op. cit.*).

However, there still seem to be many controversial problems as presented by Hofker (1971), Towe (1971), and Sliter (1974). As a rule, the specimens examined in this study did not show a

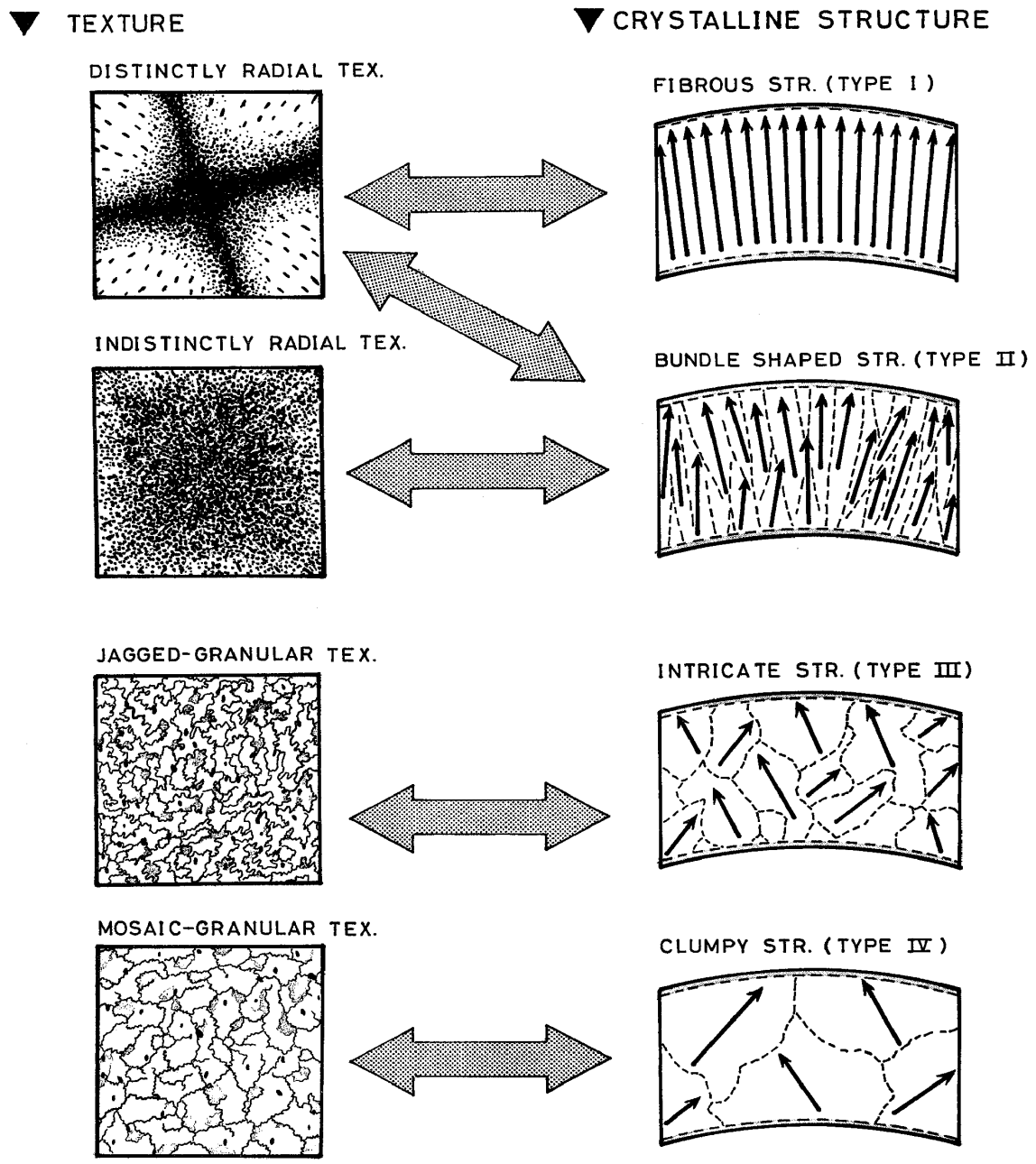


Fig. 5. The relationships between the texture under a polarized light microscope and crystalline structures on SEM micrograph.

typical bilamellar structure. Most forms have a monolamellar construction. Scanning electron micrographs demonstrate that a parting line—passage (Reiss, 1963a; Reiss and Schneiderman, *op. cit.*), median layer (Hansen and others, *op. cit.*), primary membrane (Hemleben, 1969a, b; Bé and Hemleben, 1970), and primary organic layer (Hemleben *et al.*, 1977) —that divides the inner calcareous layer from the outer calcareous layer (=inner lining and outer lamella of Reiss) is not always defined by a sharp line, and it appears in a rather discontinuous manner. The characters vary markedly in the species studied, and may sometimes appear to

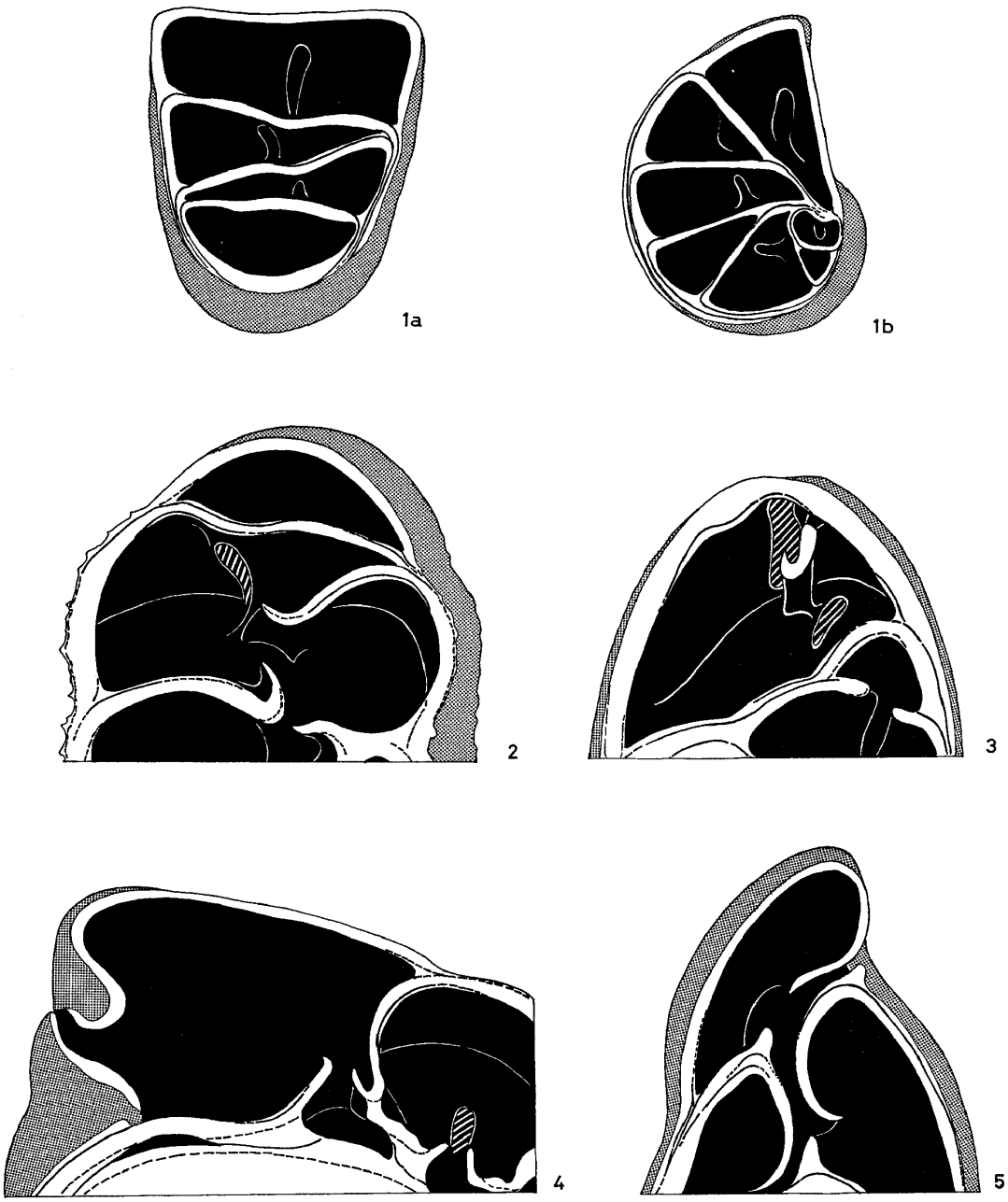


Fig. 6. Lamellar structure of some species of the Cassidulinidae. 1a, b, *Globocassidulina crepidula* (Kuwano); 2, *G. decorata* (Sidebottom); 3, *Evolvocassidulina belfordi* Nomura, sp. nov.; 4, *Burseolina pacifica* (Cushman); 5, *Cassidulina carinata* Silvestri.

show intraspecific differences. These organic layers, therefore, appear spongy, plated (Pl. 5, fig. 5), beaded, all standing out in relief to some extent from the etched surface, and incised features due to the preservation. Moreover, none of the studied species have such incorporated elements in the organic layers as the non-secreted euhedral crystals observed in the median layer of some species of *Heterolepa*, *Neoeponides* and *Stomatorbina* by Hansen, Reiss and Schneidermann (1969), Hansen and Reiss (1971), Bellemo (1976) and Hansen (1979).

Figure 6 (1–5) diagramatically illustrates the lamellar pattern in the final to

antipenultimate chambers in some species. In the final chamber wall the organic layer can not be traced for its entire extent, but is mostly found near the suture and the aperture, presenting the appearance of a bilamellar structure.

In the penultimate and antipenultimate chambers, the layering structure is more complex. The calcitic layer formed in the final chamber is superimposed conformably on the previous chamber wall, thinning out toward the earlier portion, although, in the septal chamber wall, the layering structure varies in different regions. Three calcitic layers are sometimes found near the posterior sutural region, where further extension of the succeeding inner calcareous layer covers the outer surface of the preceding septal chamber wall, in the way that a septal chamber wall is constructed in rotaliid (Reiss, 1957).

The final chamber wall of such species as *Globocassidulina decorata, G. tsuchidai, G. depressa, Evolvocassidulina belfordi, Paracassidulina nabetaensis* and *Burseolina marshallana minima,* is either two layered or nonlamellar. In *Paracassidulina* the region of apertural ridge is multilayered; very thin and at least four calcitic layers are recognizable in the antipenultimate chamber. *Globocassidulina crepidula* (Fig. 6, nos. 1a, b), in horizontal and transverse sections, shows a typical monolamellar construction, whereas in the antipenultimate septal chamber wall the organic layer is also partially visible.

The primary tongue, secondary tongue, apertural plate and the apertural flap in the final chamber are all basically nonlamellar, but the region near the chamber wall rarely shows the organic layer.

From the observations of various specimens, the following points are further noted.

1) The number of calcitic layer is fundamentally in proportion to the number of chamber, and the calcitic lamellae formed by each episode appear to be continuous over the entire test.

2) Previously formed septal chamber walls are partly covered by the inner layer of the subsequent chamber wall. This may lead to the multilayers of the septal chamber wall.

3) The respective calcitic layers bounded by the organic layers do not change their structure.

5. Tests, sutures, chamber forms and arrangements

In the Cassidulinidae, the external shape of the test and the chamber form of a species extremely vary with the ontogenetic development. But every cassidulinid species has fundamentally the same structural plan of biserial chamber arrangements.

Tests: The external shape of the test is intimately related with the chamber arrangement and shape, and apertural forms. The different external test morphology, therefore, results from the different chamber form and arrangement. The following fundamental types are distinguishable in three dimensions: lenticular, discoidal, oval, subglobular to globular, crosier-shaped, semi-ellipsoidal, subquadrate, and fusiform.

When viewed on projection, the outline of these tests are also referred to the term circular, subcircular, lobulate-subcircular, semi-circular, teardrop-shaped, broadly oval, oval, lobulate-oval, compressed-oval, lenticular, subquadrate, circulo-linear or subauriculate, fusiform, triangular, and cuneate.

The peripheral margin of the tests in profile view (axial periphery) also varies in various degree. They are classified based on the degree of compression and the development of keels as follows (see Fig. 7): keeled (wide carina), *e.g., Cassidulina carinata*; keeled (narrow carina), *e.g., Islandiella yabei*; acute, *e.g. Globocassidulina brocha*; subacute, *e.g., G. neo-*

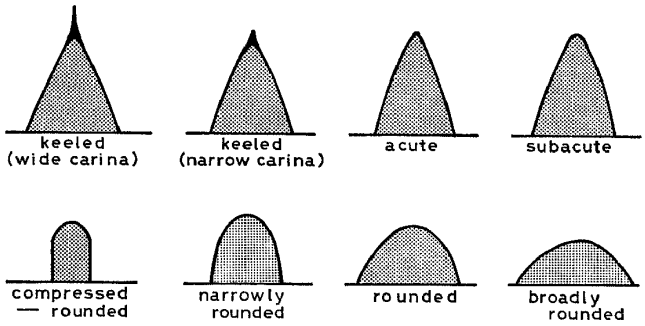


Fig. 7. Types of test periphery in the Cassidulinidae.

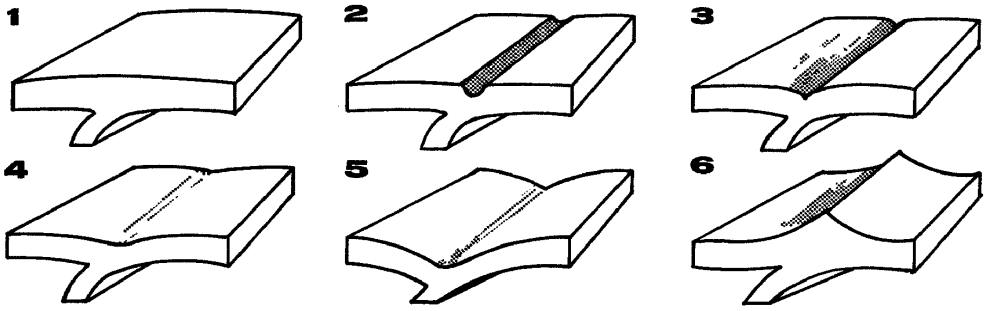


Fig. 8. Types of suture in the Cassidulinidae.

brocha; compressed-rounded, *e.g.*, *Paracassidulina miuraensis*; narrowly rounded, *e.g.*, *P. sagamiensis*; rounded, *e.g.*, *G. bisecta*; broadly rounded, *e.g.*, *Burseolina pacifica*.

Sutures: A variety of chamber shapes and arrangements stipulate for the arrangement of sutures in various ways. Furthermore, as mentioned in the section of ornamentation, sutures may be marked by various ornamental features. These modified sutures will supply valuable information on their taxonomy.

In an external appearance on test surface, the arrangement of sutures is classified into three types. One is a radial arrangement closing the umbilicus. This type is represented by *Islandiella islandica*, *Globocassidulina bisecta*, *G. depressa*, *Cassidulina norvangi*, *etc.* The second is a tangential arrangement with a clear or translucent shell material in the umbilicus. This feature is most clearly demonstrated in *Islandiella sublimbata*, *I. yabei*, *I. norcrossi*, *I. helenae*, *Globocassidulina brocha*, *G. crenulata*, *Cassidulina carinata*, *Paracassidulina neocarinata*, *etc.* The third type is undulated sutures as shown in *Globocassidulina undata*.

In cross section, the sutures are divided into six types (Fig. 8). Flat suture (Fig. 8, no. 1): This suture is flush with the chamber wall, and is usually recognized as a sutural limbation without pores. In some species including *Islandiella yabei* and *I. sublimbata*, these sutures are typically developed. Sutural groove (Fig. 8, no. 2): This suture is characterized by a U-shaped depression. *Globocassidulina parva*, *Paracassidulina sulcata*, *P. miuraensis*, and *Lernella inflata* have these sutural shapes. Sutural notch (Fig. 8, no. 3): This suture is characterized by a V-shaped or wedge-shaped depression. In *Globocassidulina crassa* and *G. patula*, this suture is typically visible. Slightly depressed suture (Fig. 8, no. 4): This suture is found in most species. Moderately depressed suture (Fig. 8, no. 5): This

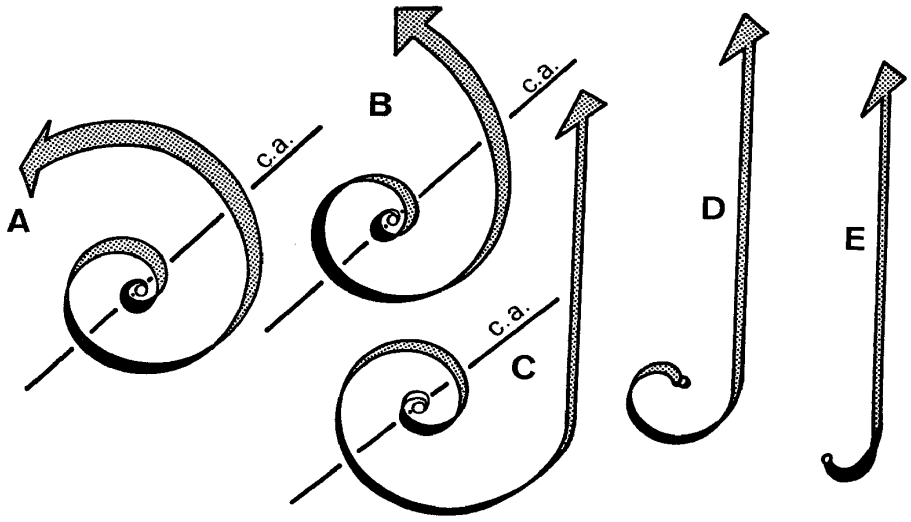


Fig. 9. Coiling types of test in the Cassidulinidae.

suture is recognizable in species having a lobulated periphery. Sutural ridge (Fig. 8, no. 6): this suture is rather restricted in *Ehrenbergina*. This suture is well shown in the earlier portion on the dorsal side of some ehrenberginid species.

Chamber form and arrangement: The shape of chamber and such structural plan as the mode of coiling can be regarded as one of the basic characters influencing test shapes. Chamber shapes have been described by various terms, which are referred to general outlines viewed rather from one direction than from stereoscopy. They are designated as broadly oval, oval, rounded-rectangular, rounded quadrate, sublunate, triangular, trapezoidal, amoeba-shaped, and lanceolate.

Coiling characters are basically divided into the following five types (Fig. 9): (a) involutely enrolled, (b) loosely enrolled or tending to uncoil, (c) enrolled with uncoiling portion, (d) slightly coiled in early portion, and (e) uncoiled or very loosely coiled in the earliest portion. In Fig. 9, the axis indicating a general direction of chamber construction is schematically illustrated by passing through the apertures of respective chambers.

6. Apertural forms and positions

Based on the external shape of apertures in fully matured forms, the following nine types can be recognized for various species of the Japanese Cassidulinidae. Figure 10 schematically illustrates these apertural types.

A Type is characterized by a narrowly elongate aperture bearing cristate tooth and sulcus on the posterior side. The cristate tooth ordinarily coalesces with the secondary tongue on the anterior side and with the lip at the posterior end. *Islandiella helenae* (A1 Type; Pl. 7, fig. 11) and *I. norcrossi* (A2 Type; Pl. 8, fig. 3) have the aperture of this type. The apertural fissure, which is formed by an externally projecting primary tongue, can not be found in this type. When viewed from the interior, the primary tongue has a columnar appearance.

B Type apparently resembles A Type, but is differentiated from the latter in having an externally projected primary tongue to form an apertural fissure. The secondary tongue is also well developed. These two tongues are, however, not combined. Thus a gap is usually found. Although the cristate tooth is recognized, some specimens of

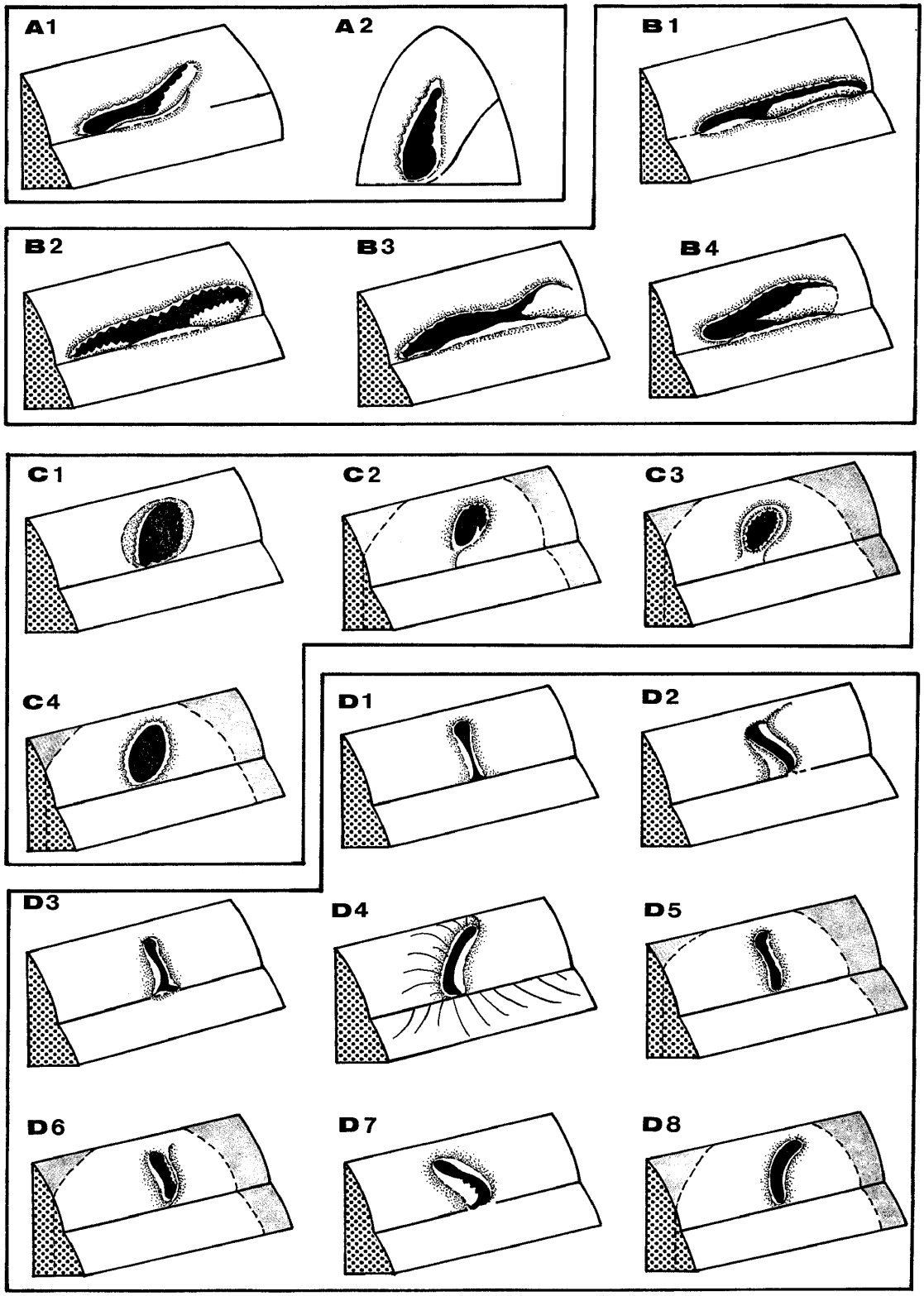
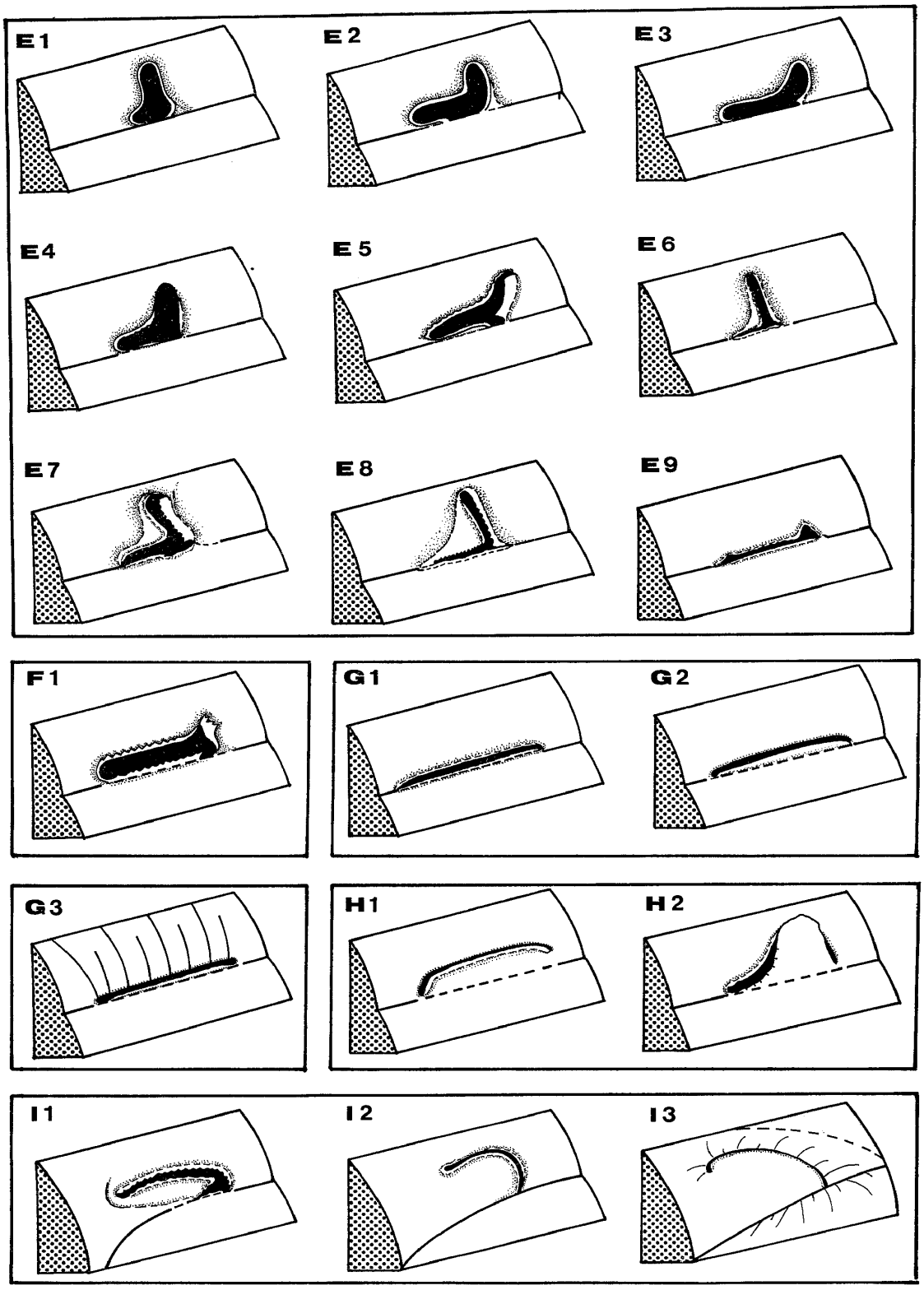


Fig. 10. Types of aperture in the Cassidulinidae. Each



type indicates apertural form at the ephebic stage.

Islandiella japonica do not have this structure (Pl. 10, fig. 4). The lips are decorated with serrated to knobbed and pustulated structures (Pl. 9, figs. 2, 3). In this type, the apertural ridge is well elevated in front of the aperture. This type is shown in *Islandiella islandica* (B4 Type; Pl. 11, fig. 5), *I. japonica* (B1 and B3 Types; Pl. 10, figs. 4, 5), *I. setanensis* (B1 Type; Pl. 11, figs. 1, 2), *I. kazusanensis* (Pl. 11, fig. 11), *I. sublimbata* (B2 Type; Pl. 9, fig. 2), and *I. yabei* (B3 Type; Pl. 9, figs. 10–12).

C Type is characterized by an oval aperture surrounded with the lip and cristate tooth. The apertures of this type are mostly situated in subterminal depressions of narrower apertural faces. It is noticeable that most species are, when viewed from the interior, only associated with the copula without the primary tongue. Moreover, a much reduced cristate tooth can be seen in some species (*e.g.*, *Cassidulinoides subcylindricus* and *Evolvocassidulina eadei*), but it is hardly discriminated from true lips. The aperture of this type occurs in radially built *Cassidulinoides subcylindricus* (C4 Type; Pl. 7, figs. 7, 8), and such granular built forms as *Globocassidulina moluccensis* (C1 Type; Pl. 11, fig. 12), *Evolvocassidulina kuwanoi* (C2 Type; Pl. 20, fig. 4), and *E. eadei* (C3 Type; Pl. 19, fig. 13). With respect to the degree of modification, the aperture of this type may be construed to be the simplest in the Cassidulinidae.

D Type is characterized by a narrow loop-shaped aperture, which perpendicularly extends from the base of aperture. The aperture is, in its external feature, composed of a cristate tooth on the posterior side and a lip on the anterior side with or without apertural ridge and apertural grooves. The tips of the cristate tooth and lip are usually serrated. When viewed from the interior, the primary tongue is fringe-shaped, but in hastilid species it does not appear. The eight forms shown in Fig. 10 represent aperture of the D Type. This type of aperture occurs in three genera *Globocassidulina*, *Evolvocassidulina* and *Hastilina*: *G. mucronata* (D6 Type), *G. undata* (D6 Type; Pl. 12, fig. 11), *G. parviapertura* (Pl. 12, fig. 5), *G. matobai* (D3 Type; Pl. 12, fig. 13), *G. pseudoquadrata* (D7 Type; Pl. 12, fig. 3), *G. venustas* (Pl. 14, figs. 4, 5), *G. gemma* (D4 Type; Pl. 13, figs. 7, 8), *G. subglobosa* (D2 Type; Pl. 13, fig. 5), *E. belfordi* (D5 Type; Pl. 20, fig. 8), *E. brevis* (D5 Type; Pl. 21, fig. 2), *Hastilina subtenuis* (D6 Type; Pl. 25, fig. 12).

E Type occurs exclusively in *Globocassidulina*, and is characterized by a tripartite feature. Namely, it consists of two apertural branches; one is parallel to the periphery of the preceding chamber, and the other is arranged perpendicularly to the *basal apertural branch* and is called *areal apertural branch*. Although the aperture of this type is fundamentally organized by two branches of almost the same length, the developmental degree of respective branches and angle between them vary in some cases with ontogenetic development. In some species, the basal branch is reduced as in E1 Type, and in another case the areal branch is strongly reduced as in E9 Type. When these two are organized at an obtuse angle, the aperture shows a crescent appearance as in E3 and E5. The cristate tooth with a sulcus is formed on the posterior side of areal apertural branch, and the lip is constructed in the anterior corner of the septal chamber wall with or without a triangular apertural flap (E7, 8). The tip of apertural rim, surrounded by the lip, cristate tooth, and the secondary tongue, is mostly serrated, but in some cases collar-shaped as shown in E1 to E4. The apertural ridge is not always formed, but developed in some species (Pl. 14, figs. 8, 9; Pl. 17, figs. 3, 4, 8, 9; Pl. 18, fig. 3). Most species with this type have the primary

tongue in internal portion, but *Globocassidulina crassa* (E9 Type) does not. The aperture of E Type is represented by the following species: *G. crassa* (E9 Type; Pl. 18, fig. 3), *G. brocha* (E3 Type; Pl. 18, fig. 8), *G. neobrocha* (E5 Type; Pl. 19, figs. 3, 4), *G. jamesoni* (E4 Type; Pl. 19, fig. 1), *G. decorata* (E7 Type; Pl. 17, fig. 8). *G. okinawaensis* (Pl. 18, fig. 2), *G. paratortuosa* (E6 Type), *G. nojimana* (E6 Type; Pl. 17, fig. 9), *G. subbisecta* (E2 Type; Pl. 16, fig. 7), *G. oriangulata* (E7 Type; Pl. 16, fig. 11), *G. rugosa* (E7 Type; Pl. 16, fig. 6), *G. parva* (E6 Type; Pl. 15, fig. 7), *G. depressa* (E6 Type; Pl. 15, fig. 11), *G. bisecta* (E6 Type; Pl. 14, figs. 8, 9), and *G. tsuchidai* (E8 Type; Pl. 17, figs. 3, 4).

F Type is mostly closely allied to the aperture of E Type in its basic construction, but somewhat differs from the latter in having a larger basal apertural branch. The lip, cristate tooth and the secondary tongue are externally protruded, presenting serrated appearances. The primary tongue is internally formed. The aperture of this type is only found in *Globocassidulina patula* (F1 Type; Pl. 18, fig. 6).

G Type is characterized by the interiomarginal elongate narrow slit, and exclusively found in the genera *Paracassidulina* and *Takayanagia*. The apertural organization is very simple, having no cristate tooth or the secondary tongue. But the secondary tongue exceptionally occurs in the internal portion of the aperture of *Paracassidulina sagamiensis*. The lip occurred in this type is usually a pseudolip formed in the septal chamber wall. The apertural ridge is very thin, but almost always formed, presenting a feature of the apertural plate. The apertural grooves are sometimes found. This type is represented by the following species: *Paracassidulina nipponensis* (G1 Type; Pl. 25, fig. 3), *P. nipponensis terebra* (G1 Type), *P. neocarinata* (G2 Type), *P. sulcata* (G3 Type), *P. minuta* (G2 Type), *P. quasicarinata* (G2 Type; Pl. 25, figs. 9–11), *P. miuraensis* (G2 Type; Pl. 25, fig. 6), *P. tomiyensis*, *P. sagamiensis* (G2 Type; Pl. 24, figs. 10, 11), *P. oshimai*, *P. nabetaensis* (G3 Type; Pl. 25, fig. 7), and *Takayanagia delicata* (G2 Type; Pl. 7, figs. 1, 3).

H Type occurs in two genera *Cassidulina* and *Lernella*. It is characterized by having an apertural plate concealing the apertural foramen. The toothplate never occurs. The sublunate form (H1) and the strongly arcuate form (H2) are discriminated by the shape of the plate. The former occurs in *Cassidulina*, presenting a hook-like structure on the posterior side, and the latter occurring in *Lernella*. The following five species represent this type: *Cassidulina carinata* (H1 Type; Pl. 23, figs. 7, 8), *C. norvangi* (H1 Type; Pl. 23, fig. 10), *Lernella seranensis* (H2 Type; Pl. 24, fig. 6), *L. inflata* (H2 Type; Pl. 24, fig. 4), and *L. ogasawarai* (Pl. 24, fig. 8).

I Type is an overturned aperture accompanied by a semicircular apertural flap on the anterior side. The primary tongue is formed internally, and is entirely covered by the septal chamber wall. The cristate tooth on the posterior side does not protrude externally. The lip is formed as a thickened rim on the tip of the apertural flap. The apertural grooves occur in some species. The aperture of this type is typically found in *Burseolina* and *Ehrenbergina*, including the following species: *Burseolina pacifica* (I1 Type; Pl. 21, figs. 6–8), *B. marshallana minima* (I2 Type), *B. bullaeformis* (I1 Type; Pl. 21, fig. 11), *Ehrenbergina carinata* (Pl. 22, fig. 10), *E. bosoensis* (I3 Type; Pl. 22, fig. 7), *E. bosoensis decorata* (I3 Type; Pl. 22, fig. 9), and *E. crispata* (Pl. 23, fig. 5).

On the other hand, when viewed from a standpoint of the apertural position, the following three forms are distinguished (Fig. 11).

A forms are almost parallel to the

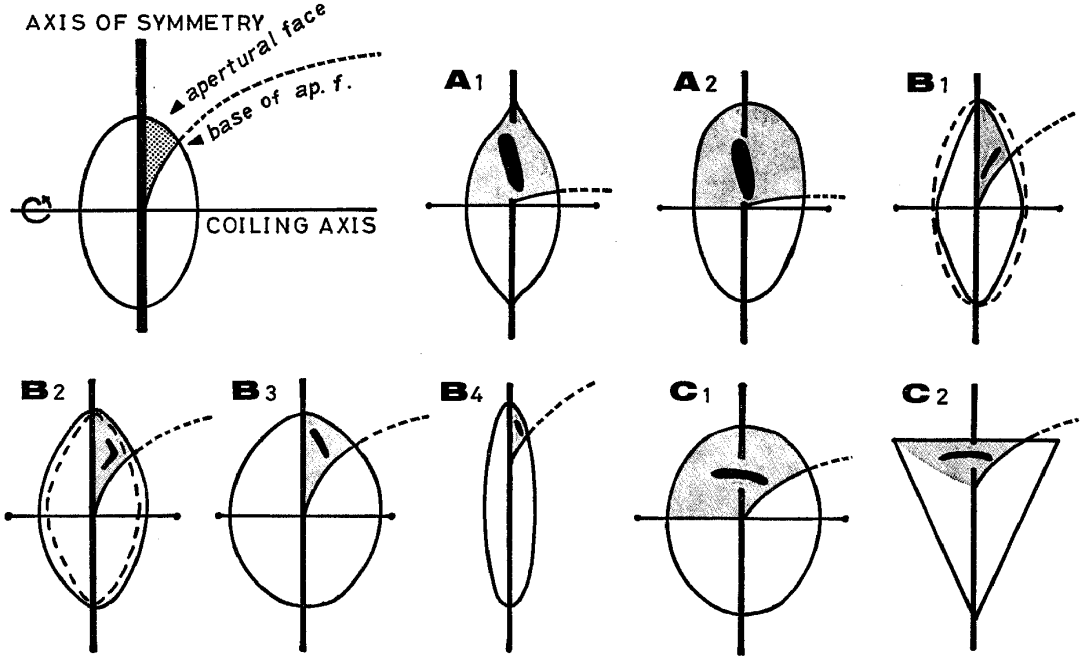


Fig. 11. Location and general form of aperture in the Cassidulinidae.

axis of symmetry in spite of a biserial chamber arrangement. *Islandiella norcrossi*, *Globocassidulina crepidula*, and *G. venustas* show the apertural position of this form. Moreover, it is noteworthy that the neanic apertures of lenticular tests are mostly set up in this manner.

B forms are recognizable as the most orthodox organization for the Cassidulinidae. The aperture usually opens at right angles to the apertural face (*e.g.*, *Globocassidulina subglobosa*) or parallel to the base of the apertural face (*e.g.*, *Paracassidulina* and *Takayanagia*).

C forms occur in the *Burseolina* and *Ehrenbergina*. In these forms, the aperture is inclined at some angles to the base of apertural face, so that it shows an overturned appearance in a ventral view. A sharp distinction is made here between these apertural forms as well as the apertural position; however, the two vary both in ontogeny and phylogeny.

7. Toothplate and other apertural modification

Toothplate was defined by Hofker (1950, 1951a, b, *et seq.*) as an inner apertural modification as follows: "The toothplate runs from one septal foramen (former protoforaminal aperture) to the next. It always originates at the border of the septal wall which is closest to the suture formed by the apertural chamber wall (now the septal wall) and the wall of former chambers on which the chamber is built." and ".... in coiled forms...., the toothplate follows the basal wall of chamber toward the next foramen, attached to this wall; its plate is standing up in the lumen of the chamber and at its highest part more or less abruptly runs down again, forming a folded lip which does not reach the basal wall again, so that a 'free folded part (Höglund)' is formed with a free border of the plate" (Hofker, 1950, p. 11). Such a characteristic arrangement of the toothplate is observable in many species of the Cassidulinidae as mentioned by many workers. Figure 12 shows schematically

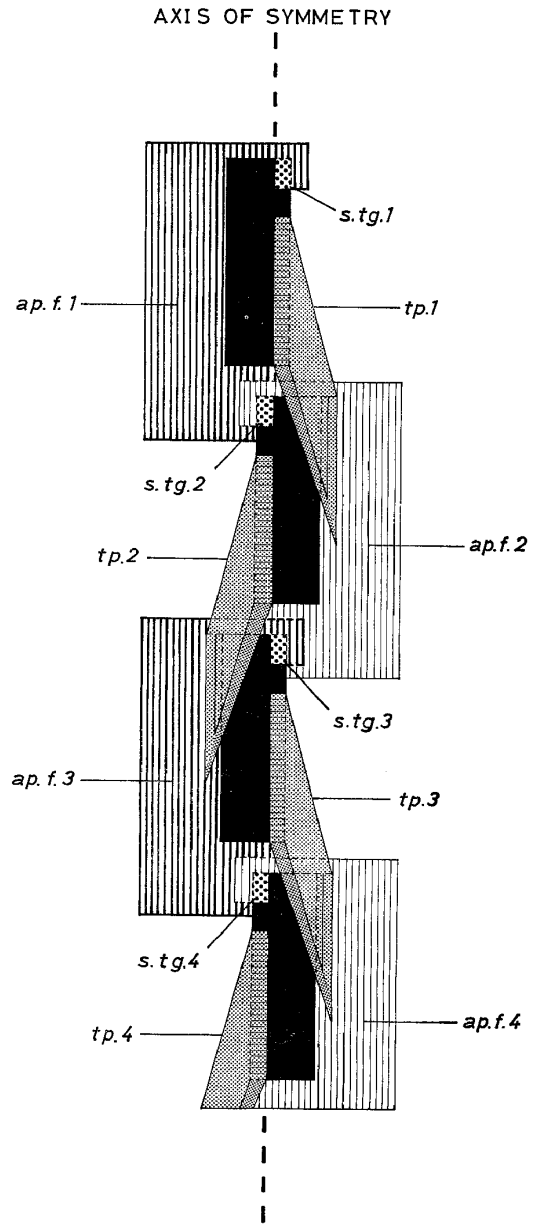


Fig. 12. Schematic diagram showing the development of toothplate (s.l.). *tp.*=toothplate (s. l.), *s. tg.*=secondary tongue, *ap. f.*= apertural face. Numbers indicate the concurrent construction of chamber formation accompanied by these parts.

the toothplate arrangement. The toothplate (*tp.* 1, 2, 3, 4, in the figure) which originates at the anterior part of the preceding apertural face (*ap. f.* 1, 2, 3, 4, in the figure) can be seen in the posterior corner of the newly formed apertural foramen. It is attached to the chamber wall on one side; most part of it is concealed by a simultaneously formed chamber wall. In these biserial chamber arrangement, the toothplate is also alternatively formed.

Before the Hofker's systematic works on the toothplate, Höglund (1945) and Brotzen (1948) payed much attention to these internal structures with great interest, and introduced many terms to define various portions of the structural elements modifying the aperture (*e.g.*, tongue, comb, wing, partition, crista, infundibulum, reflecta, *etc.*). However, Hofker stressed that these terms are absolutely homogeneous with the toothplate. In later studies, this term has come to be overzealously applied in a much wider sense. Furthermore, many other terms with respect to the apertural modifications formed in a number of ways have been proposed by various workers. Accordingly, there has been much confusion among authors who did descriptive works. For example, the toothplate of the Cassidulinacea has been called in such varied ways as internal tooth, plate, apertural tooth, tongue, lip-like structure, projecting tooth, projecting tongue, *etc.*

During the course of this study, the writer realized that the term toothplate should be used only for general features formed by the infolding of septal chamber wall, and that the toothplate is worthless in the comparative works as far as recognition of its presence or absence is concerned, but important for evaluation of variable features to determine the relationships of various species as well as genera. Some species (*e.g.*, *Evolvocassidulina kuwanoi*) do not have any internally extending free part, but do have an externally projecting part. In some species (*e.g.*, *E. eadei* and *Cassidulinoides subcylindricus*), the internal free part is absent and the external part is much reduced. Some species (*e.g.*, *Globocassidulina brocha*) have a free fold-

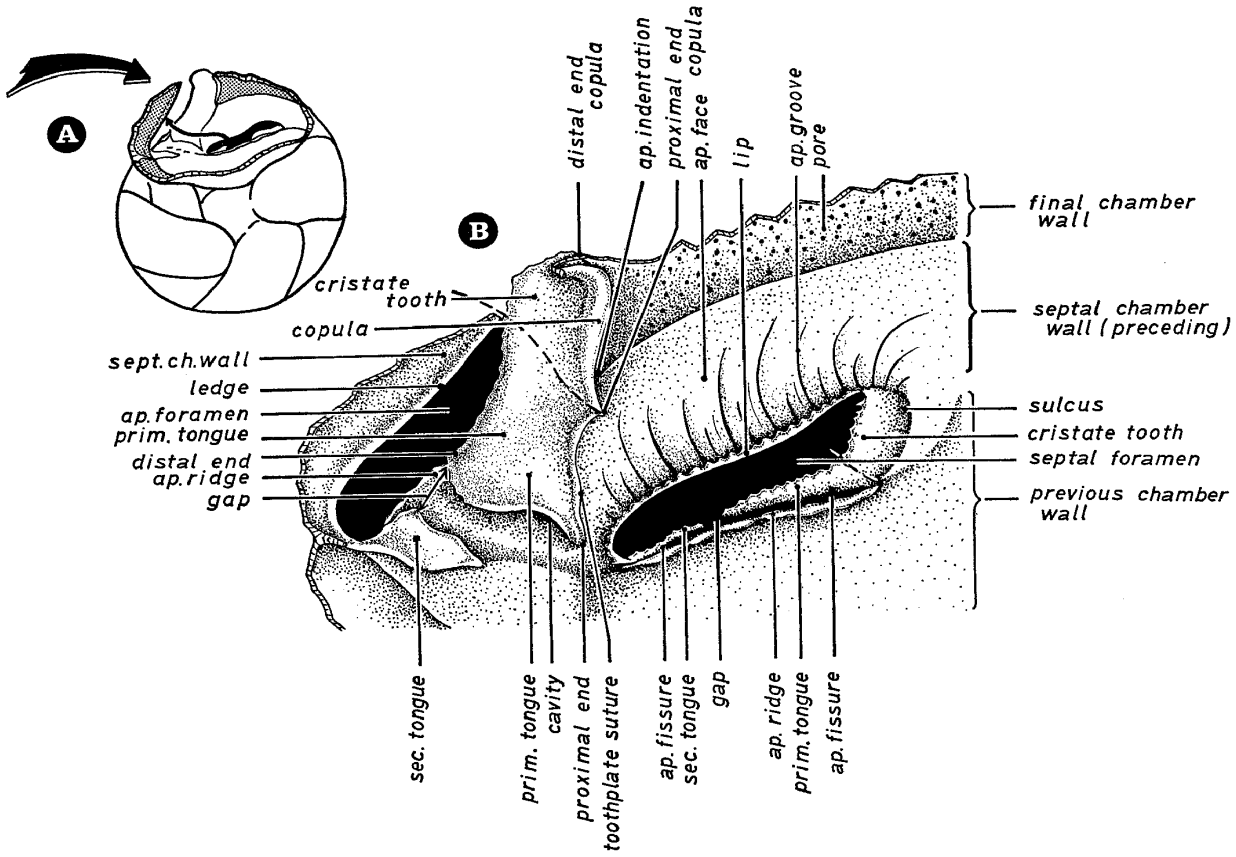


Fig. 13. Idealized apertural modification of the Cassidulinidae.

ing internal part as well as a very reduced external part. These facts clearly indicate that the toothplate is not a consistent feature. It must be emphasized that the toothplate alone does not necessarily indicate generic relationships. Very useful suggstions were given by Glaessner (1954) and Belford (1966). The latter author stated: "The broad application of the term toothplate obscures possible generic relationships in that structural similarities which may enable homologous features to be recognized in different genera are not considered. . .With the recognition of the finer details of the test as important morphological features it seems to me necessary to distinguish between features formed in different ways, or differently situated, and to give them different names." (Belford, 1966, p. 12).

The present writer agrees with Belford (*op. cit.*) and feels that the definition of the basic position of fully developed or rudimentary toothplate under different descriptive terms is necessary to accomplish a more precise taxonomic classification. The term used by the present writer to describe various portions are schematically illustrated in Figs. 13 and 14.

The free folding part of the toothplate is called *primary tongue*. The term *cristate tooth* is used for the externally projecting portion of the distal part of the primary tongue. It is always present in most of the species regardless of their developmental degree of the primary tongue in the appearance of a lip-like or flange-shaped structure (Pl. 16, fig. 11; Pl. 18, figs. 3, 8). A conjugating portion of the cristate tooth and the infolding chamber wall is called *copula*. In summary, the toothplate involves the

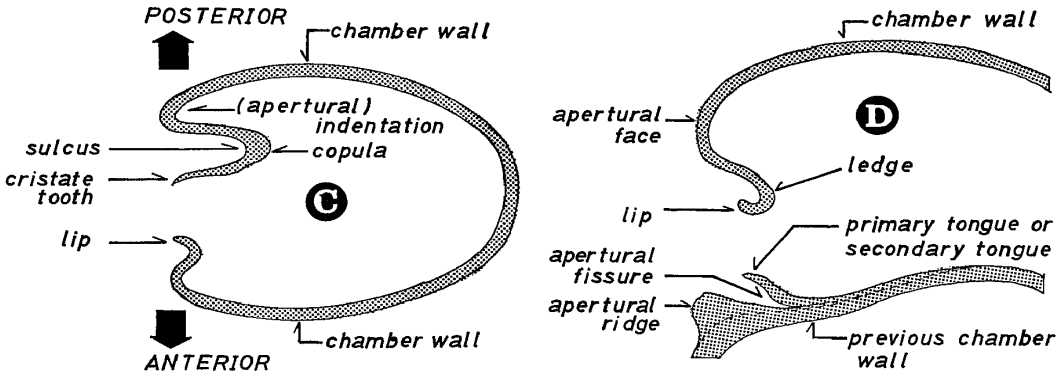


Fig. 14. Schematic diagram of aperture. C=vertical section of the final chamber, D= horizontal section of the final chamber.

following three distinct constituents: primary tongue, cristate tooth, and copula.

On the other hand, the anterior septal chamber wall is attached to the adjacent previous chamber wall; when attaches to it, a free part is likewise formed (Fig. 13). This smaller tongue structure is here called *secondary tongue*, which is typically developed in some islandiellid species (Pl. 9, fig. 8; Pl. 10, fig. 7; Pl. 11, fig. 2). This structure is homologous with plate of Saidova (1975) and Rodrigues *et al.* (1980).

The space formed between the tooth-plate and septal chamber wall are referred to as *cavity*, *apertural fissure*, *sulcus*, and *apertural indentation*. The internal space between the primary tongue and the septal chamber wall is called cavity (Pl. 10, fig. 1; Pl. 10, fig. 6), which is connected with *apertural fissure* on one side. The apertural fissure, which is formed between the cristate tooth and the septal chamber wall as well as between the secondary tongue and the septal chamber wall, can be seen externally (Pl. 10, fig. 4; Pl. 11, fig. 5). This structure is present only in those species having a well-developed primary tongue (*e.g.*, *Islandiella yabei*, *I. japonica*, *I. setan-aensis*, *etc.*), but is not formed in the neanic to earliest ontogenetic stages even in these typical species (Pl. 10, fig. 8). The incised space between the cristate tooth and the chamber wall is called sulcus (Pl. 8, figs. 3, 10; Pl. 9, fig. 2; Pl. 12, fig. 3; Pl. 13, figs. 7, 8; Pl. 16, figs. 6, 11; Pl. 17, figs. 4, 8; Pl. 18, fig. 2; Pl. 20, fig. 8; Pl. 21, fig. 11). The sulcus corresponds to the upper part of the copula. The space between the copula and the septal chamber wall is called apertural indentation. In most cases, the primary and secondary tongues are not attached to each other. The term *gap* is used herein to designate a discontinuous feature formed between the two tongues. However, some species having a subterminal aperture do not have the gap. The term *ledge*, which was originally designated by Belford (1966) and followed by Rodrigues *et al.* (1980), is applied to a thickened apertural inner rim. The ledge continues into the copula in distal portion. A thick shell material in the proximal part of the aperture which is called *apertural ridge* is sometimes formed on the periphery of the previous chamber. This structure can be seen in various species. It is thickest in *Islandiella* and thinner in *Paracassidulina*.

A *lip* is always situated on the distal end of the septal chamber wall and is shown as an everted peristomal thickening (Fig. 15). The lip surrounds the apertural foramen in association with the cristate tooth on the posterior side and the secondary tongue on the anterior

proximal side. Exceptionally, however, the lip occurring in some species of *Paracassidulina* is formed by a local thickening of the septal chamber wall just around the apertural foramen (Pl. 5, fig. 6; Pl. 25, fig. 6; Fig. 17). The *pseudolip*, as called here after the pattern of construction, must be distinguished from the lip mentioned above.

These apertural modifications in various shape can be seen in many species of the Cassidulinidae. However, four genera *Burseolina*, *Ehrenbergina*, *Cassidulina* and *Lernella* possess different apertural modifications. *Burseolina* and *Ehrenbergina* have an aperture overturned on the ventral side at least in mature stages, so that the lower inflated and flattened portion, actually formed by the extension of the anterior septal chamber wall, covers the apertural foramen. The *apertural flap* is proposed for this septal modification. In these genera, the base of the toothplate is attached to the apertural flap (Pl. 21, figs. 7–9). The term *apertural plate* proposed here designates a plate-like structure formed by the extension of the posterior septal chamber wall along the base of aperture (Pl. 23, figs. 7, 8, 10, 12). Two genera *Cassidulina* and *Lernella* have this structure.

The septal chamber walls, including the toothplate, apertural flap, and apertural plate, are essentially imperforate. Another term apertural face can be applied to these imperforate septal walls.

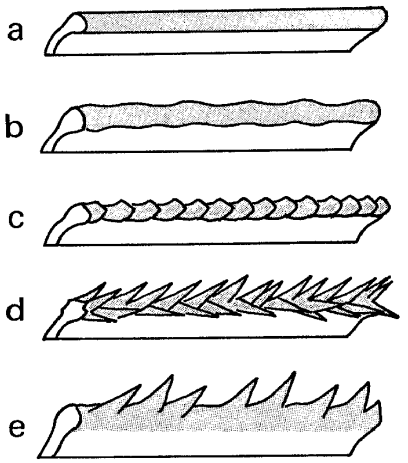


Fig. 15. Types of lip and cristate tooth. a=tube-like structure, b=undulated structure, c=nodose structure, d=strongly serrated structure, e=sporadically serrated structure.

8. Ornamentation

Structurally and genetically different elements on the test surface have collectively been referred to as ornamenta-

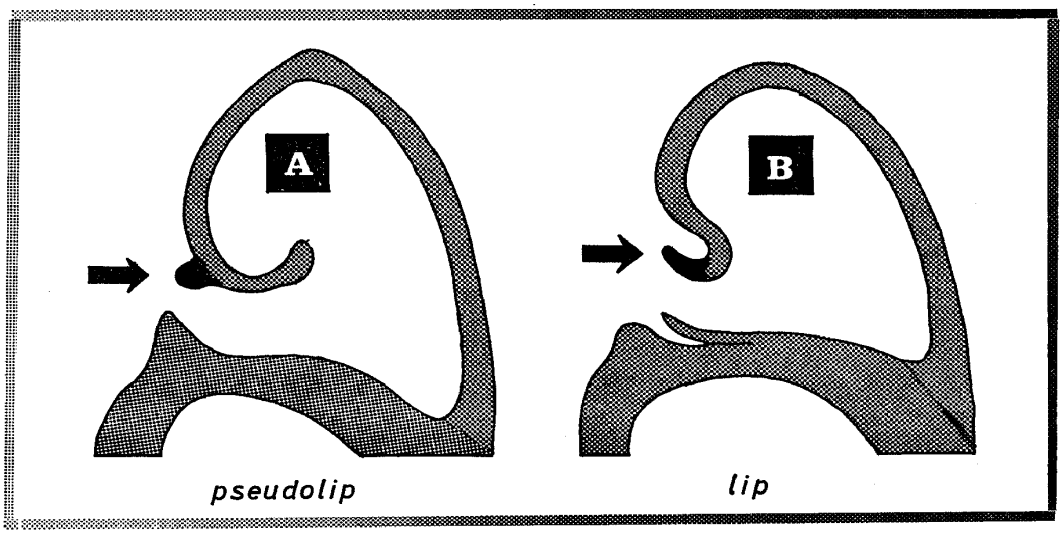


Fig. 16. Shematic diagrams of lip and pseudolip. Lip is formed by a local increment of crystal units on septal chamber wall.

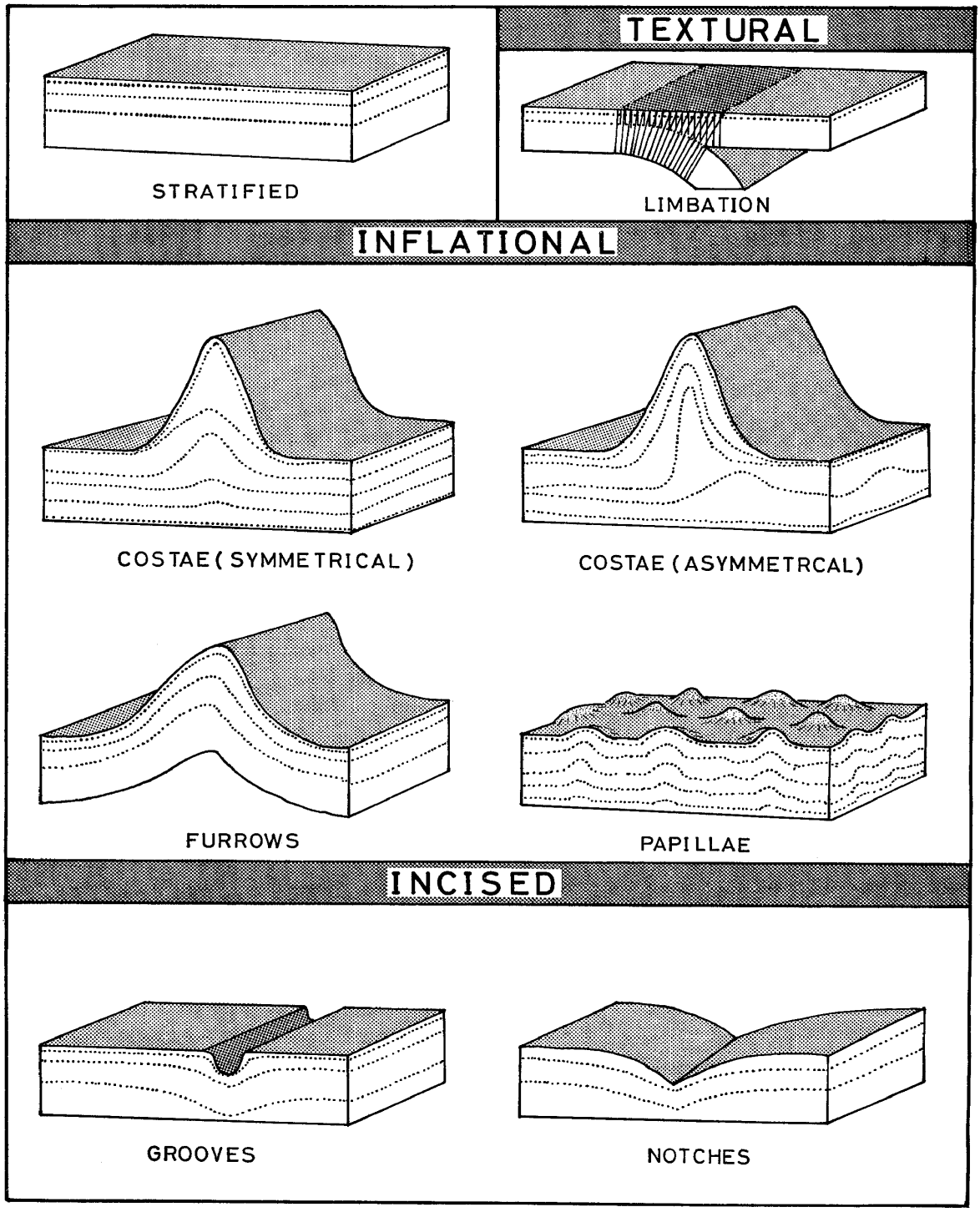


Fig. 17. Surface ornamentation of the Cassidulinidae, and lamellar patterns. Limbation in textural ornamentation is formed by the interdigitating of preferred orientations of crystal elements (solid lines).

tion. In the Cassidulinidae, there are various kinds of ornamentation; carinae, costae, grooves, furrows, keels, limbations, lumps, mammillae, notches, papillae, reticulations, ridges, spines, and striae. Any of these features, which are

recognized as an integral part of the test walls, can be basically ascribed to one of the three types—(1) inflational, (2) incised, and (3) textural (Fig. 17).

(1) Inflational ornamentation is formed by local thickening of shell material caused by the prominence of lamellar superposition during the subsequent calcification. This ornamentation involves carinae, costae, furrows, keels, lumps, mammillae, papillae, ridges, and spines.

Keels are formed by the collapse of a chamber wall along the test periphery, and are recognizable as a distinct sharpening of the peripheral chamber margin. The keels are invariably devoid of perforation and so are the peripheromarginal areas referable to Reiss' "carinal band" (Reiss, 1957). None of the keels of the Cassidulinidae shows any evidence of a carinal canal or scattered canaliculus as recognized in planktonic species. In a tangential section, they are composed of crystal elements which are longest at the center and shorten laterally. It is noticeable that arrangements of crystal elements in keels are comparable between the granular and radially built walls. Electron micrographs of keels of *Cassidulina carinata* and *Paracassidulina neocarinata* which have an intricate crystalline structure (opticaly jagged-granular texture) show that the crystal elements of respective aggregates are almost parallel with each other and less branching (Pl. 4, fig. 5).

From an ontogenetical point of view, the primoidal keels are formed in the neanic chamber as demonstrated by the megalospheric ontogeny of *Islandiella sublimbata*, *I. norcrossi*, and *I. helenae*.

The peripheral carinae have also been recognized in the same sense as the keels. Depending on development of carina, narrow to wide, and in some cases serrated carinae were observed. *Globocassidulina crenulata* sp. nov. typically shows these serrated carinae.

The ridges and costae are formed by the thickening of calcite layers in some calcification episode. They appear not only on weak parts of the chamber wall, but also on relatively flat surfaces. These ornamentations are characteristically weaker on ontogenetically later chambers than on the earlier ones. In the Cassidulinidae, ridges and costae are mostly arranged in a reticulate pattern (*e.g.*, *Globocassidulina decorata* and *G. nojimana*). From a standpoint of comparative anatomy, the crystalline structure of ridges and costae is almost identical with that of the keels.

In the layering structure, two basic types are observed (Fig. 17); one is a symmetrical type concordantly covering the earlier costae and the other is an asymmetrical type discordantly covering the earlier ones. During the successive calcification episodes, older costa becomes higher, and at the same time, new costa is also formed. By the respective calcification, the costae, particularly reticulate ones, may be combined with one another and covered with further calcitic layers. Thus, when the costae are harmonically covered with successive calcitic layers, a symmetrical type may be formed. On the other hand, when the conjugating or branching costae are covered an asymmetrical type may be formed.

The furrows are formed by the outward bending or arching of the chamber wall with stratified layers (Fig. 17). There is no evidence of strongly elongated crystal elements. The furrows are most typically recognized in some ehrenberginid species as median furrow (*e.g.*, *Ehrenbergina bosoensis* and *E. crispata*).

The papillae and mammillae are recognized as small rounded lumps on the test surface or the inside of the apertural plate of some lernellid species. Although these terms have been used in the same sense, papillae were recognized in this paper as the features on the test surface (*e.g.*, *Globocassidulina undata* and *G.*

mucronata).

The spines are here recognized as narrowly and rapidly lengthened pillars or protuberances. In the genus *Ehrenbergina*, peripheral spines are well developed, and sometimes median spines are also present. From a ultrastructural or textural point of view, they seem equivalent to such protuberances as ridges and keels; the crystal elements forming spines are arranged almost parallelly to a spine and are made of somewhat larger crystal units. On the other hand, penultimate and antipenultimate peripheral spines of *Ehrenbergina carinata* have hollows (Pl. 23, fig. 3). The *spine hollows*, as here called, are restricted to those spines formed in later ontogenetic stages. Around the spine hollows, the arrangement of crystal elements is identical to that of chamber walls, but pores are absent. A similar inner structure was once observed by Molčiková (1978).

The functional significance of spine hollows is not fully understood at present, but at least two hypotheses may be presented. One is to maintain specific gravity of an adult test, and the other is to strengthen the spine itself. As for the spine hollows of ehrenberginid, none of the canals is connected with hollows and main chamber, so that gas exchange between them seems to be unlikely. The hollows moreover occur on larger spines. Consequently, the present writer favors the latter hypothesis.

(2) Incised ornamentation is formed by local thinning of the normal calcitic layer (Fig. 17), and shows anastomosing or pectinated features depressed in various degree. This type involves grooves, notches, and striae.

The grooves include *sutural grooves* and *apertural grooves*. The former occurs in *Globocassidulina parva* (Pl. 15, fig. 10), *Paracassidulina sulcata*, *P. tomiyensis*, *P. miuraensis* (Pl. 25, fig. 6), and *P. nabetaensis*. These grooves are U-shaped in cross section, and are traceable as sutures. In such species as *P. tomiyensis* and *P. sulcata*, the grooves are branched and wedged out. *Globocassidulina gemma* (Pl. 13, figs. 7, 8), *G. crenulata*, *Paracassidulina nabetaensis* (Pl. 25, fig. 7), *P. sulcata*, *Ehrenbergina crispata* (Pl. 23, fig. 5), *E. bosoensis* (Pl. 22, fig. 9), and *E. bosoensis decorata* have apertural grooves, giving an impression of wrinkles radiating out of the aperture. Although they are usually U-shaped in cross section, some cases show a shallowly wrinkled or underdeveloped surface as shown in *Globocassidulina tsuchidai* (Pl. 17, fig. 4) and *Paracassidulina nabetaensis* (Pl. 25, fig. 7). In addition, when viewed from the developmental process, two types of apertural grooves are recognizable; one is formed ontogenetically in later stages (*e.g.*, *Paracassidulina sulcata*, *P. nabetaensis*, and *Globocassidulina tsuchidai*), the other appears originally in proloculus aperture as shown in *G. gemma* (Pl. 13, fig. 9).

The notches are recognized as *sutural notches* which have a wedge shape in cross section. A striated surface is formed by the uni-directional arrangement of slit-shaped pores (Pl. 12, figs. 8, 9; Pl. 13, figs. 6, 12; Pl. 20, fig. 10). In *Globocassidulina gemma*, the slit-shaped pores are accompanied with slight, striae-like depressions on the wall (Pl. 12, fig. 9). These depressions are ordinarily restricted to the earlier test surface facing the apertural face and radiate out of the aperture (Pl. 13, fig. 5).

(3) The third type of ornamentation is the textural. It concerns mainly sutural limbation. The textural oranamentation, including inflational and incisional ornamentations, was originally defined by Smout (1954) in the Rotaliidea. According to him, this type is formed by local changes of such textures as crystalline structure and perforation. However, all ornamentations are, as mentioned above, formed by local changes of crystalline structure. Therefore, the

keels, ridges, spines, *etc* may also be construed as the textural type. The term textural is herein not applied in the aforementioned sense; it forms local complexity of the crystalline structure which is caused by interfingering and interweaving of respective crystal units or elements (Fig. 17). This complexity produces different optical properties and limbate sutures are formed. The degree of limbation is, therefore, due to the thickness of chamber wall and interconnecting angles between the respective chamber walls. In most cases, the limbation is well visible in the radially built wall, including distinctly and indistinctly radial textures.

9. Perforation

The term *perforation* used in this study is collectively applied to abundant small pores on the test surface, and the term *pores* follows the definition of Hansen and Lykke-Andersen (1976). Namely, pores are equipped with an organic tubular lining, and may be subdivided by organic diaphragms which correspond to each successive lamella (Pl. 5, fig. 5) as clarified by many workers (*e.g.*, Sliter, 1974, fig. 4). The term *pore tubule* is adopted from Hansen and Lykke-Andersen (*op. cit.*) for the tunnel communicating external and internal portions of the test wall.

Recently, much attention has been paid to size, pattern and fabric of pores by using electron microscope, and these features are at present regarded as an important systematic characteristic. But they also show considerable variations in the size and shape of pores in individual specimens, although the pore pattern or fabric is recognized as the characteristic of species (Loeblich and Tappan, 1964a). In the following paragraphs, the shape of pores on the outer and inner test surfaces, their modifications and structure of pore tubules will be described.

Pores on the outer test surface of the Cassidulinidae show a wide variation and are divided into five types according to a plane view—rounded pores, funnel-shaped pores, slit-shaped pores, oval to elongate-oval pores, and irregular pores (Fig. 18). These external features are mainly due to a figurative expression of calcitic lamella and veneer.

The rounded pores were usually found in the final and penultimate chambers in all the species and earlier portions of some restricted species — *Globocassidulina, Cassidulina, Evolvocassidulina, Takayanagia,* and *Islandiella* (Pl. 7, figs. 5, 10; Pl. 8, figs. 4, 5; Pl. 12, fig. 4; Pl. 14, fig. 3; Pl. 15, figs. 4, 5, 10; Pl. 17, fig. 6; Pl. 18, fig. 4; Pl. 19, figs. 6, 10; Pl. 20, fig. 3; Pl. 21, figs. 3, 4; Pl. 22, figs. 1, 8, 11; Pl. 24, fig. 2; Pl. 25, figs. 2, 5). The diameter of these pores varies considerably. The smallest pore (0.1 μm) was found in the antipenultimate chamber of *Paracassidulina*; it is almost sealed over by the outer veneer layer. The largest pore (approximately 2.5 μm) was found in *Evolvocassidulina*; it is not covered with the veneer. As a rule, the pores on the final chamber are smaller and flush with the surface, whereas those on the earlier chambers tend to become larger and somewhat depressed. The latter features are most typically shown in *Globocassidulina pseudoquadrata* (Pl. 12, fig. 4) and *Evolvocassidulina brevis* (Pl. 21, fig. 4; compare with the penultimate pores in fig. 5). Pore size also varies in different portions of one specimen. In the case of *Takayanagia delicata*, pores near the umbilicus are larger than those in the peripheral portion.

The funnel-shaped pores (Pl. 23, fig. 9) found around the umbilical portion of *Cassidulina carinata* are formed by a progressive enlarging during the calcitic lamella formation. They show a constricted feature of pore tubules like a concentric funnel formed by the earlier calcitic lamellae. The diameter of outer

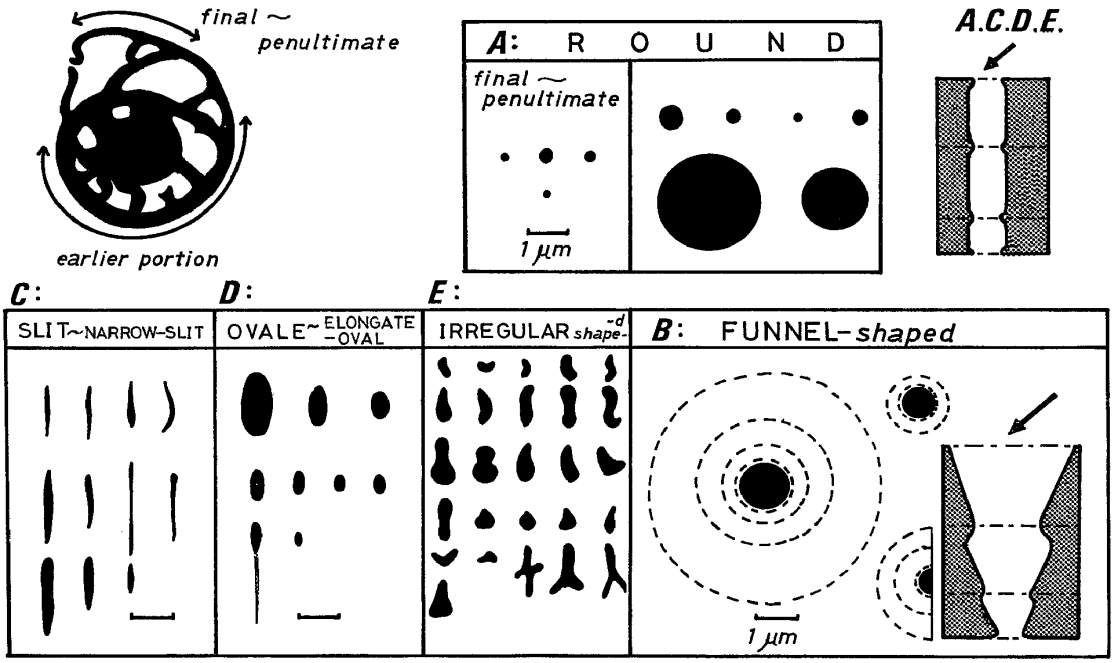


Fig. 18. Types of pore on the external test furface.

funnel varies even in the same portion; the largest one attains about 5.6 μm. It is noteworthy that these funnel-shaped pores gradually change into the rounded pores toward the periphery.

The slit-shaped pores (Pl. 11, fig. 8; Pl. 12, figs. 2, 8, 9; Pl. 13, figs. 6, 12; Pl. 17, figs. 7, 12; Pl. 22, fig. 6; Pl. 25, figs. 1, 8) are confined to the earlier portion of some species of *Globocassidulina*, *Burseolina* and *Paracassidulina*. The length of a slit is largest in the earliest portion (2.3 μm), and gradually shortens toward newly formed chambers; in the final chamber, slits appear to be rounded. The most notable feature is that every slit of pore is arranged parallelly toward the aperture. Consequently, a striated feature is formed by a regular arrangement of these slit-shaped pores. However, in some species having a rugged surface structure, the outline of slit-shaped pores is modified by crystalline mounds of the inflational ornamentation (Pl. 11, fig. 8; Pl. 17, fig. 7).

Oval to elongate-oval pores (Pl. 7, fig. 10; Pl. 10, figs. 2, 10; Pl. 13, fig. 1; Pl. 14, fig. 7; Pl. 16, fig. 10; Pl. 17, fig. 7; Pl. 19, fig. 9; Pl. 20, fig. 6) occur in some species of *Islandiella*, *Evolvocassidulina*, *Globocassidulina*, *Hastilina*, and *Lernella* in association with occasional rounded pores. These pores appear in the earlier portion of the test, and the size is variable; the largest one attains 1.6 μm in length and 0.7 μm in width. As in the case of slit-shaped pores, their long axes are arranged almost regularly in one direction, but they all tend to be parallel to the direction of the inflational ornamentations. Some pores of this type are constricted in the middle like a gourd (Pl. 14, fig. 7).

Irregular pores were found in most species. In a plane view, the pores are triangular, trapezoidal, subauriculate, cuneate, pyriform, bifurcate, cross, hemispherical, clavate, gourd-shaped, and the like. It is difficult to decide whether these various features are originally formed or resulted from post-mortem etching. However, some features are considered to be original in some specimens. As documented by Grell (1973)

and Hemleben *et al.* (1977, 1979), shell resorption has been considered to be a common phenomenon among calcareous foraminifera. In many cases, therefore, these irregular pores may be brought about as a result of shell resorption.

Compared with variously shaped pores on the outer test surface, pores on the inner test surface except for the proloculus are not sealed by the inner veneer and rather uniform in size, presenting an original form of rounded openings (Fig. 19). Pores on the final and penultimate chambers are rounded and are very slightly depressed. Pores on the earlier chambers are commonly depressed, and give a pitted appearance. The pitted

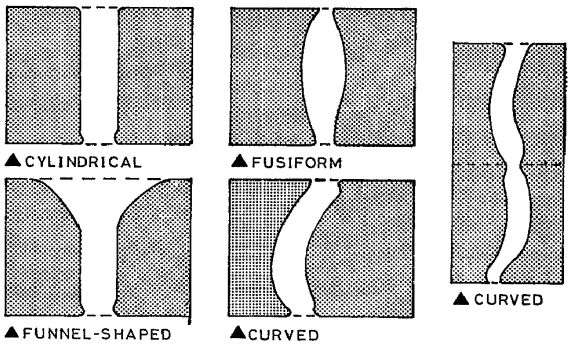


Fig. 19. Basic shape of pore tubules.

appearance is more profound near the sutural region, and pore openings tend to become larger (Pl. 13, figs. 10, 11). Depressed pores are sometimes accompanied with a flat surface around the pores (Pl. 24, fig. 3) which is called *pore terrace* following Walker (1976), who studied ecophenotypic variations throughout the year. Another type of pores on the test surface was found in *Globocassidulina nojimana*, which has a concentric ridge around the pore terrace (Pl. 18, fig. 1). This ridge is here called *pore swell* in order to discriminate it from such pore modifications of planktonic species as steep side, sinuous ridges (Srinivasan and Kennett, 1976), residual ridges and built up ridges (Benjamini and Reiss, 1979). Concentric grooves around the pores are rarely formed in *Globocassidulina bisecta* (Pl. 15, fig. 3). The pore rim introduced by Sliter (1974) is used for these features. Although the pore rim is formed by the surface membrane and slightly inflated (Sliter, *op. cit.*, figs. 7A, 9, 10D), grooved natures, which closely resemble the present structure, were surely indicated around the pores in his fig. 9. It is remarkable that the pores can not found on the inner surface of proloculus in any of the species (Pl. 7, fig. 4; Pl. 13, fig. 9; Pl. 15, fig. 1), which may be attributed to a complete sealing by the inner veneer.

The structure of pore tubules, which possess marked constrictions and distensions corresponding to the lamella, is basically classified into the following four types; cylindrical, fusiform, curved, and funnel-shaped (Fig. 20). The cylindrical type is the most common. The curved type rarely appears to be sinuate.

Pore constriction was usually found on the interlamellar boundaries of consecutive growth lamellae and in the basal portion of the innermost test; it prominently chokes up the pore tubules. In addition to this pore constriction, the existence of organic diaphragms is known in the constricted portions. This feature is demonstrated in sectioned specimens of *Paracassidulina nabetaensis* (Pl. 5, fig. 5).

10. Discussions

The processes of mineralization in foraminifera are very enigmatic. There have been no consistent opinions in which the process of crystallization is universely accepted. But, at least, two related processes — crystal nucleation and subsequent crystal growth — can be considered to be the fundamental of mineralization (Wilber, 1964, 1980; Taylor *et al.*, 1969; Wada, 1980). In this sense, it may be inferred that the crystallographic preferred orientation of calci-

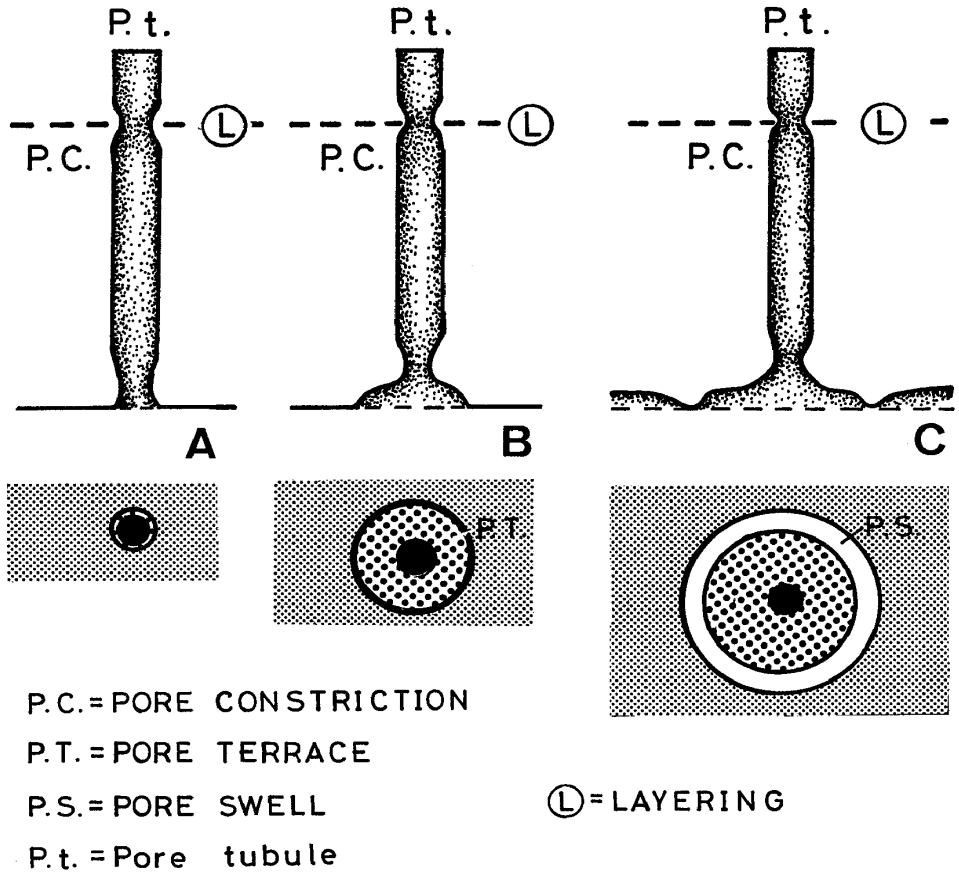


Fig. 20. Relationships between the pore tubule and the shape of pore on the inner test surface, and their modification.

fied wall is easily explained by a template model of calcification. One, however, feels a difficulty to depend entirely on this model, because the complicated arrangement of the crystal units and elements, and the branching crystal elements in three dimensions contradict the hypothesis of the crystal growth on the basis of a two dimentional template. If the nucleation and the subsequent crystal growth take place in contact with the organic template, we can not explain the curved and branching nature of crystal elements. Towe (1971) pointed out that the primary membrane does not act as the template, that is, "there is no evidence of a gradational calcification process,.. calcification and test construction are independent of sequential chamber formation or lamination." Spindler (1978) observed that the organic lining is missing in the terminal chamber of *Heterostegina depressa*. If this is true, the organic lining does not present the template for calcification. Towe also noted that the epitaxy and the compartment theories fail to account for calcification (Towe, 1972, *fide* Lipps, 1973).

Angell (1979) supported the hypothesis of Towe (*op. cit.*). In his figures of the crystal growth (Angell, 1979, pl. 4, figs. 17–20), crystallites are formed within the compartment of a membrane complex surrounding the cytoplasmic anlage with randomly located nucleating points. This feature may be deducible from the intricate crystalline structure. The respective crystal units, shown in the bundle-shaped, intricate, and clumpy crystalline structures, are inferred to be

formed by the nucleation separately distributed within modified areas of anlage membrane. But, as seen in the bundle-shaped crystalline structure, most of the crystal elements, which gather together to form the crystal units, originates from the basal part of walls. This may indicate that the nucleation, in most cases, takes place on the secreted membrane of the anlage. This interpretation does not contradict the Angell's observation on an optically radially built *Rosalina floridana*.

As pointed out by Towe (1971) and Angell (1979), simple ideas of compartment and epitaxy may not serve as an almighty theory for calcification. It is, however, quite difficult to explain the calcification without these ideas. There can be little doubt that the biologically controlled organic precursor is necessary prior to calcification. Concerning the organic matrix surrounding the crystals, two types are recognized; one is the intracrystal organic matrix which envelops the crystal elements, and the other is the intercrystal organic matrix which envelops the crystal units. The former is much thinner than the latter, as clearly demonstrated by Hansen (1970) on a three dimensional network. From the morphological features, it is postulated that these two matrices have a different role during the crystal development. That is, the intracrystal organic matrix serves as an active substrate of this organic matrix, and the incipient crystal successively grows epitaxially. On the other hand, the intercrystal organic matrix serves as a passive substrate, which regulates the crystal growth and the form of the crystal units. This does not correspond to the lamellae in the test wall. The curved and branching crystal elements may be ascribed to some kinds of effects, such as crystal defects, inclusion, and other influence of an electrical potential (Towe and Thompson, 1972; Lipps, 1973; Taylor, 1973; Conger, Green and Lipps, 1977). Furthermore, the crystal morphology as well as the crystalline structure is influenced by the physico-chemical conditions of a crystallizing solution (or organic gel), rate and form of crystal growth, and external environmental condition, such as temperature and salinity. Taylor (1973) noted that the structural changes in various bivalve shells take place as a possible result of the precipitation of calcium carbonate with protein, adopting the metallurgical example (Chalmers, 1958; Henish, 1970), as in the case of the crystallization during the solidification of impure melt. In the aragonite crystals of the nacre in pearl oyster (*Pinctada martensii*), slow-growing crystals of winter, are likely to be large with well-defined euhedral crystals, whereas crystals at a time of rapid shell growth may be smaller and more rounded (Wada, 1961). In the foraminifera, such a relationship between the crystal size and growth rate has yet to be investigated.

Among various factors influencing the crystalline structure, temperature may more seriously affect structural differentiation in the Cassidulinidae. Optically radial textures are restricted to the Japan Sea province influenced by cold water conditions, and the granular textures are abundantly distributed in the southern Pacific province. It is, however, impossible at present to estimate whether the textural changes occur from the granular to radial or *vice versa* with changes in temperature. Many other factors may also collectively act, as shown in some exceptional species. For example, *Reissia hystrix* and *Favocassidulina favus*, both having the radial texture, are adapted to the tropical region. On the contrary, *Cassidulina norvangi* is dominant in the cold water region. Further detailed analyses are required on living organisms under various environmental conditions before attacking these

problems, one of the outstanding enigmas of biomineralization.

The function of the toothplate (s.l.) has been interpreted by many workers in various ways. No observations have ever been made on living animals, although Glaessner (1954) stressed that such observations are very important to confirm various hypothetical functions advanced by various researchers. Brotzen (1948) considered the toothplate as a protective device to prevent the protoplasmic effluence from the aperture. Hofker (1950) interpreted its function as follows: (1) protection of apertural region, (2) basal structure for pelagic purpose, (3) point of affixture for adhering protoplasm to the substrate, and (4) the formation of fine canals through which locomotive protoplasm streams towards the surface of the test. Scott (1978a), who studied the shell design of some species of *Bolivinita*, considered it to function as an impedance of the passage of cytoplasm. Most recently, Coleman (1980) expressed that the toothplates within the agglutinated tests consisting of uniserially arranged chambers, such as *Clavulina*, have an internal supportive role to strengthen the tests.

However, these hypotheses seem to be still somewhat insufficient to explain the function of cassiduline toothplate. The present writer considers that the toothplate may serve both to control the cytoplasmic stream like a rudder and to plan the chamber arrangement and chamber form, being regulated by the apertural shape. Therefore, the construction of toothplate will first occur during the course of chamber formation as in the case of *Patellina corrugata* (Berthold, 1976b). This is inconsistent with Scott's interpretation that the construction would be in the last phase. The toothplate formed in the anterior part of the septal chamber wall in the preceding aperture may deflects the cytoplasmic bulge to one side. This process would produce the biserial chamber arrangement in successive chamber formation. Moreover, the position and shape of the primary tongue and cristate tooth may control test morphology as well as chamber form. Apertural plates and apertural flaps are considered to have a similar functional significance to impede the cystoplasmic stream.

Pores are uncalcified during the chamber formation as other workers have suggested. In *Patellina corrugata*, the organic granular material, filling the pore tubules, prevents calcification (Berthold, 1976a). Concerning its function, however, there has been a controversy, particularly as to whether pseudopods can pass through the micropores. Myers (1935), Arnold (1954) and Hansen (1972b) considered that the pores serve as outlets for pseudopods. Hansen (*op. cit.*) depicted the pseudopodial extrusion from the pores in *Amphistegina* by SEM. On the other hand, Angell (1967), Towe (1971), Banner and Williams (1973), Sliter (1974), Berthold (1976a) and Hemleben *et al.* (1977) suggested that the sieve plates inside a pore preclude the free exchange of protoplasm. No living forms of the Cassidulinidae have been examined, so that their functions are unknown. But the interpretation of Angell (1967) and others may be supported, because the slit-shaped pores arranged orderly in one direction may not be formed if the pseudopods make their entrance and exit through the pores. The pores probably have the function of intaking and excreting soluble substances, as considered by Berthold (*op. cit.*).

Such surface ornamentations as costae, keels, ridges, and grooves are genetically controlled and may strengthen the test. Also they may be influenced by ambient environmental conditions as pointed out by Hendrix (1958) and Douglas (1979).

SYSTEMATIC DESCRIPTION

Order Foraminiferida Eichwald, 1830
Suborder Rotaliina Delage and Hérouard, 1896
Superfamily Cassidulinacea d'Orbigny, 1839

This was assigned to a superfamily by Loeblich and Tappan (1961). In their subsequent paper (1974, p. 38), the following diagnosis was given for the Cassidulinacea s.s.: "The restricted Cassidulinacea included those forms with basically high trochospiral to biserial chamber arrangement, and slit-like or loop shaped aperture, commonly with internal tube or toothplate."

The following families are included by Loeblich and Tappan (1974) in this superfamily:

Family Pleurostomellidae Reuss, 1860
  Subfamily Pleurostomellinae Reuss, 1860
  Subfamily Wheelerellinae Patters, 1954
Family Annulopatellinidae Loeblich and Tappan, 1964
Family Caucasinidae N.K. Bykova, 1959
  Subfamily Fursenkoininae Loeblich and Tappan, 1961
  Subfamily Caucasininae N.K. Bykova, 1959
Family Tremachoridae Lipps and Lipps, 1967
Family Delosinidae Parr, 1950
Family Loxostomatidae Loeblich and Tappan, 1962
Family Cassidulinidae d'Orbigny, 1839

The principles of their definition of the suborder and superfamilies are based upon the chemical composition of wall and its microstructure such as radial or granular arrangement of crystals. They (1964b, p. 17) stated: "In the classification used by the writers, test mineralogy and wall microstructure are regarded as of primary importance, for these skeletal features are determined by the biochemical nature of the secreting protoplasm. According to Galloway (1933, p. 15), 'The wall structure, whether gelatinous, chitinous, granular, hyaline, fibrous, alveolar, porcellaneous or arenaceous, seems to be the most constant character of the genera, subfamilies and families. When once a particular wall material or structure is acquired it seems to be persistent.' There are many isomorphs among the different mineralogical and textural forms, and the chamber arrangement may change with ontogeny in a single specimen. Thus the uniserial forms or planispirally wound tubular nonsepatate forms of differing test compositions are clearly isomorphs and true relationships must be sought elsewhere."

However, their statements are not likely reasonable to divide cassidulinids at such higher taxonomic levels as family and superfamily. The changes in wall structure may not always occur in these taxonomic levels, because the present study indicates that they change most probably at the generic level.

KEY TO GENERA OF JAPANESE CASSIDULINIDAE*

I. Aperture elongate loop to tripartite (Apertural type: A, B, C, D, E, F)
  A. Test globular to discoidal
    1. Radial wall texture ..... *Islandiella*
    2. Granular wall texture .... *Globocassidulina*
  B. Test elongate
    1. Loosely coiled in early stage.. *Hastilina*
    2. Closely coiled in early stage
      a. Radial wall texture.. *Cassidulinoides*
      b. Granular wall texture .... *Evolvocassidulina*
II. Aperture curved slit with apertural plate (Apertural type: H)
  A. Test discoidal ..... *Cassidulina*
  B. Test elongate ..... *Lernella*

* *Cassidulinella*, *Favocassidulina*, *Orthoplecta*, *Reissia*, and *Stichocassidulina*, which appear in Loeblich and Tappan's classification, are omitted from this key because wall structure and internal characters have never been and are not fully investigated.

III. Aperture interiomarginal narrow slit (Apertural type: G)
  A. Radial wall texture ..... *Takayanagia*
  B. Granular wall texture .... *Paracassidulina*
IV. Aperture arcuate slit with apertural flap (Apertural type: I)
  A. Test globular ..... *Burseolina*
  B. Test trihedral
    Granular wall texture ..... *Ehrenbergina*

Family Cassidulinidae d'Orbigny, 1839, emended

Emended diagnosis: – Test free, lenticular, subglobular or elongate; chambers biserially arranged throughout, alternating chambers enrolled at least in early stage, but in later stages may be uncoiled; wall calcareous, perforate, optically granular to radial in texture; aperture interiomarginal slit, elongate, and tripartite, extending upward from base of last apertural face at a certain angle, with or without toothplate; toothplate extending inward from aperture to septal foramen.

Remarks: – The family Cassidulinidae herein emended is interpreted in a broad sense so as to include both forms with radial and granular wall textures. Loeblich and Tappan (1964a) proposed the family Islandiellidae on the basis of a radially built wall as well as the presence of apertural modifications such as toothplate, in contrast to the granular built family Cassidulinidae. Moreover, they assigned these two families to different superfamilies. Namely, the family Islandiellidae was placed in the superfamily Buliminacea and the family Cassidulinidae in the superfamily Cassidulinacea. They considered that wall microstructure and composition are of prime importance for phylogenetic classification, and the identical chamber arrangement and test form may have developed independently through parallel evolution in forms with radial and granular walls.

However, these features may not be acceptable as the bases for dividing the family and subfamily. Towe and Cifelli (1967) in their research on ultrastructures of some species indicated that the granular and radial wall types would appear relatively easily to derive one from the other and a major taxonomic division of the hyaline foraminifera into radial and granular appears to be unsubstantiated.

Although the microstructure of each of these granular and radial types shows variation to some degree within the same species, the present writer did not observe any radical change from granular to radial type or *vice versa*. For this reason the writer treats the wall structure as a significant character at the generic level. As already mentioned, the toothplates are herewith regarded as a specific character.

Concerning the taxa of hyaline foraminifera (Order Rotaliina) above the family, on the basis of the present knowledge available, the present writer believes that such fundamental chamber arrangements as biserial, triserial, uniserial and so on will provide the most reasonalby acceptable criteria for classification. It is worthwhile to cite here the following statement given by Todd and Low (1967, p. A37):

"... This philosophical question is unreasonable. One might argue that the now-rejected Brady (1884) classification that included the agglutinated Textularinae and calcareous Bulimininae together in the Textulariidae and that gave more weight to manner of coiling than to wall composition, is no less justifiable than the combining of the radial Islandiellidae with the granular Cassidulinidae. Still, 80 years after Brady's work, we are unable to prove satisfactorily that one feature or another can serve as an infalliable basis for classification. Rather we look for combinations of features and find in general resemblances a basis for family classifications. The better classification is the one that unites like forms and does not set them apart."

According to Tappan (1976), the family Cassidulinidae is regarded as a derivative from the Loxostomatidae in Paleogene and the family Islandiellidae from the family Bolivinidae in Cretaceous. Such workers as Galloway (1933), Asano and Nakamura (1937a), Hofker (1951b, 1956b), and Reiss (1963c) considered *Virgulina* (=*Fursenkoina* Loeblich and Tappan) as the ancestral form of the Cassidulinidae. Both Glaessner (1945) and Sigal (1952) considered that *Cassidulina* was evolved from *Bolivina*. Cushman (1948a) considered *Ceratobulimina* and *Pulvinulinella* (=*Epistominella* Husezima and Maruhasi) as the ancestral forms of this family. Pokorný (1958) considered either one of the trochospiral or planispiral forms as the ancester of *Cassidulina*.

Genus *Islandiella* Nørvang, 1958, emended

Islandiella Nørvang, 1958, p. 26, 27.
Cassilamellina Voloshinova, 1960, p. 59 (type, *Cassidulina californica* Cushman and Hughes, 1925).
Planocassidulina Gudina, 1966, p. 69 (type, *Cassidulina norcrossi* Cushman, 1933).
Cassidulita Sellier de Civrieux, 1968, p. 156, 157 (type, *Cassidulina norcrossi* Cushman subsp. *australis* Phleger and Parker, 1951).
Cassandra Gudina and Saidova, 1968 (*fide*, Saidova, 1975, p. 341).
Discoislandiella Saidova, 1975, p. 346, 347 (type, *Cassidulina smechovi* Voloshinova, 1952).

Type species: – *Cassidulina islandica* Nørvang, 1945, p. 42, text-figs. 7, 8d-f: Recent, off Iceland.

Emended diagnosis: – Test free, lenticular to subglobular in outline; periphery carinate to rounded; chambers broad to elongate, biserially arranged throughout, planispirally enrolled, with a set of triangular portion at the periphery; sutures slightly depressed to flush with surface, limbate, radially or tangentially arranged, showing clear shell material in umbilicus; wall calcareous, thick or thin, hyaline, finely perforate, optically radial in texture, pore tubules distinct in thin section; surface commonly smooth and polished; aperture elongate, interiomarginal foramen with toothplate on posterior side and secondary tongue on anterior side; toothplate distinct, varied in shape, usually extending from posterior side of aperture to anterior corner of preceding septal chamber wall, with cristate tooth or primary tongue externally protruded. *Stratigraphic distribution*: – Paleocene to Recent.

Remarks: – In 1958, Nørvang erected the genus *Islandiella* for those cassidulinid species having a radial wall texture and internal tooth, as the distinct from other cassidulinid species having a granular wall texture and no internal tooth. He considered at that time that the association of a radial wall and an aperture with an internal tooth is an eminent character and of more than specific level. This was followed by Loeblich and Tappan (1964a) who distinguished it at the level of superfamily on the basis of wall structure and the presence or absence of toothplate. However, both radial species without toothplate (*e.g.*, *Cassidulinoides subcylindricus*) and granular species with toothplate (*e.g.*, most species of *Globocassidulina*) can occur. This means that attempts by Nørvang (1958) and Loeblich and Tappan (1964a) to subdivide the Cassiduline foraminifera based upon the combination of these criteria at the suprageneric level is not warranted. The writer, therefore, would like to recognize the wall structure as having an intrinsic value for only the generic classification. It is most appropriate, therefore, to place the genus *Islandiella* in the family Cassidulinidae, and Loeblich and Tappan's family Islandiellidae is herewith abandoned.

As shown by numerous synonymic changes, there have been different opinions expressed with regard to the taxonomic interpretation for the test shape, arrangement and form of chamber, and

apertural character of this genus. The present writer considers, however, during the course of this study, that there are no satisfactory grounds for separating this genus into manifold genera.

Cassilamellina was proposed by Voloshinova (1960) based upon *Cassidulina californica* Cushman and Hughes. Loeblich and Tappan (1964a) and Voloshinova *et al.* (1970) put *Cassilamellina* in the synonymy of *Islandiella*, whereas Saidova (1975) still considered *Cassilamellina* a valid genus. According to Saidova (*op. cit.*), characteristics are those which can be found in the apertural construction and the two internal plates, which correspond to the primary and secondary tongues in this paper. However, these features can be seen in islandiellid species and are not entirely restricted to her *Cassilamellina*.

As may be seen in *I. norcrossi* (Cushman), another difficulty arises from the recognition of chamber forms and uniserial appearance in arrangement. Gudina (1966) proposed *Planocassidulina*. Subsequently, Sellier de Civrieux (1968) erected *Cassidulita*. Both authors emphasized triangular chambers and the uniserial arrangement in their new genera. All specimens of *I. norcrossi* passed under the present writer's observation, however, do not show typical uniserial arrangement, but incipient biserial one in a later portion. Anatomical observation of *I. norcrossi* also shows that the toothplate is formed alternately to the axis of symmetry, which strongly indicates that the chamber arrangement is fundamentally based on the biserial construction.

In Japan, this genus has been recorded from Miocene to Recent sediments, as the genus *Cassidulina* or sometimes *Islandiella*.

Islandiella islandica (Nørvang), 1945

Pl. 1, figs. 2a–c; Pl. 11, figs. 4–9

Cassidulina islandica Nørvang, 1945, p. 42, text-figs. 7, 8d–f; Cushman, 1948b, p. 75, pl. 8, figs. 13a–c; Loeblich and Tappan, 1953, p. 118–120, pl. 24, figs. 1a, b; Cooper, 1964, p. 102, pl. 6, fig. 21; Ishiwada, 1964, pl. 7, fig. 96; Lagoe, 1977, p. 127, pl. 5, fig. 12.

Islandiella islandica (Nørvang). Nørvang, 1958, p. 27, 28, pl. 6, figs. 1a, b, 2–5, pl. 7, figs. 6a, b, 7a, b; Vilks, 1969, p. 49, pl. 3, fig. 3; Chiji and Konda, 1970, pl. 9, figs. 9, 10; Knudsen, 1971, p. 247, 248, pl. 7, figs. 22–25; Feyling-Hanssen, 1976, p. 357, pl. 7, figs. 4–9; Knudsen, 1976, pl. 1, figs. 7–9; Serova, 1978, p. 100, pl. 4, fig. 7.

Cassilamellina islandica (Nørvang). Gudina, 1966, p. 66, 67, text-figs. a, b, pl. 7, figs. 2, 3, pl. 8, fig. 2.

Description: – Test medium, circular to subcircular in side view, oval in edge view; periphery broadly rounded, distinctly lobulate; chambers inflated, about four pairs in last whorl; sutures distinct, slightly curved on surface, moderately depressed; aperture elongate to rounded subtriangular at the base of last apertural face with fragile cristate tooth concealing part of it; wall pretty thick, distinctly perforate, earlier portion of the test slightly rough, but the rest smooth, transparent.

Polarizing microscopy: – In transmitted light, thin sections showing wall pierced by fibrous pore tubules, and chamber and septal walls showing undulatory extinction. Fragments in Lakeside cement showing distinctly or in some cases indistinctly radial in texture.

SEM observation: – Test microtopography on earlier chambers somewhat rugged (Pl. 11, fig. 8), but progressively becoming flat toward later chambers (Pl. 11, fig. 9); pore shapes well corresponding to structure of test microtopography; pores slit-shaped on earlier portion, while rounded, flush, and more numerous on later chambers (Pl. 11, figs. 8, 9); difference of pore shapes being caused by secondary calcitic lamellae. Average length of long axis of slit-type pore 1.1 μm; average diameter of rounded type 0.5 μm; pore density 17 pores per $20 \times 20\ \mu m^2$. Aperture B4 Type (Pl. 11, figs. 4, 5); inner structure

revealing aperture formed by infolding of septal chamber wall, cristate tooth on posterior side and small secondary tongue in anterior corner; lip of C type formed on distal end of septal wall; copula reaching proximal end of preceding septal foramen; primary tongue fringe-shaped (Figs. 22, 23); apertural ridge short and somewhat undulated. Etched and fractured cross section showing wall structure of II (A) Type.

Type and occurrence: – Hypotype, Pl. 1, figs. 2a-c, IGPS 97153A, sample OG–20, Wakimoto Formation, Akita Prefecture.

Remarks: – Specimens referred to *I. islandica* occurred commonly at many localities of the Japan Sea borderland. They are characterized by its medium-sized subglobular test with lobulate periphery, somewhat inflated chambers arranged four pairs in final whorl.

These features in young forms are closely similar to those of *Globocassidulina bisecta*. In addition to these characters, the inner structure is also quite similar to each other. Thus it is difficult to allocate the specimens either to *I. islandica* or to *G. bisecta*, by their morphology alone. Nevertheless, an essential difference exists in the perforation and wall structure; namely, *G. bisecta* has III-Type wall structure (jagged-granular texture).

This species differs from *I. californica*, *I. setanaensis*, and *I. japonica*, which have more larger test, more thickly calcified wall, smooth and polished surface, and usually 5–7 in the final whorl of matured specimens.

The notable feature of this species is the aperture which changes with its ontogenetic development. Juvenile forms have an oblique aperture with cristate tooth on its posterior side and present a subglobular appearance. A similar feature is shown in the specimens figured by Nørvang (1958, pl. 7, figs. 6, 7).

Ontogeny and measurements:

IGPS	Sample	Length	Width	Thickness	Fig. 21
97154–1	OG–20	0.13 mm	0.13 mm	0.12 mm	(1)
97154–2	–	0.17	0.16	0.14	(2)
97154–3	–	0.21	0.19	0.17	(3)
97154–4	–	0.27	0.22	0.17	(4)
97154–5	–	0.27	0.23	0.21	(5)
97154–6	–	0.30	0.25	0.22	(6)
97154–7	–	0.34	0.28	0.23	(7)
97154–8	–	0.37	0.32	0.27	(8)
97154–9	–	0.39	0.32	0.29	(9)

Occurrence in studied area: – Found commonly in Pleistocene deposits of the Japan Sea borderland occurring in samples KR–5; ST–5–7, 10; OG–1–3, 5, 7, 8, 12, 14, 19, 20.

Previous record of occurrence: – Recent, off Iceland (Nørvang, 1945, 1958); Recent, Arctic Ocean (Cushman, 1948b; Loeblich and Tappan, 1953); Recent, Chukchi Sea, Arctic Ocean (Cooper, 1964); Recent, northern Pacific around Japan (Ishiwada, 1964); Quaternary, Siberia (Gudina, 1966); Recent, Canadian Arctic (Vilks, 1969); Recent, off Okushiri Island, Hokkaido, Japan (Chiji and Konda, 1970); late Quaternary, Denmark and Norway (Michelsen, 1967; Knudsen, 1971, 1976); upper Pleistocene, Clyde Foreland Formation, Baffin Island (Feyling-Hanssen, 1976); Recent, Central Arctic Ocean (Lagoe, 1977); Neogene, Kamchatka (Serova, 1978); late Pleistocene, St. Lawrence Lowlands, Canada (Cronin, 1979).

The occurrences are restricted to the Arctic regions.

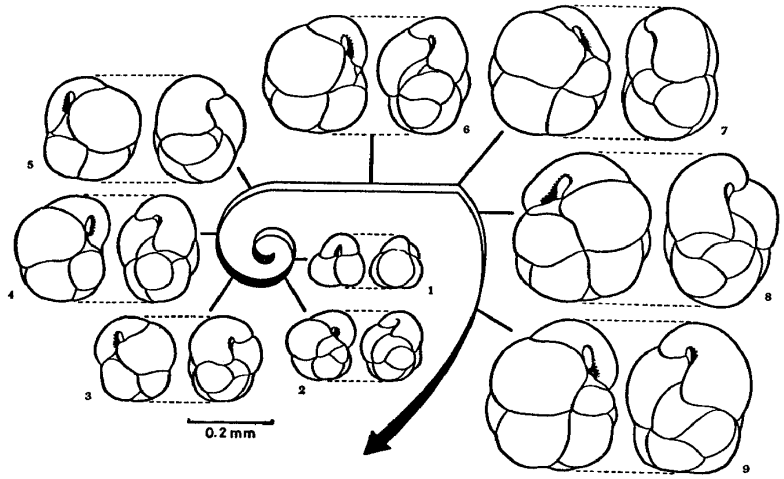


Fig. 21. Ontogeny of *Islandiella islandica* (Nørvang).

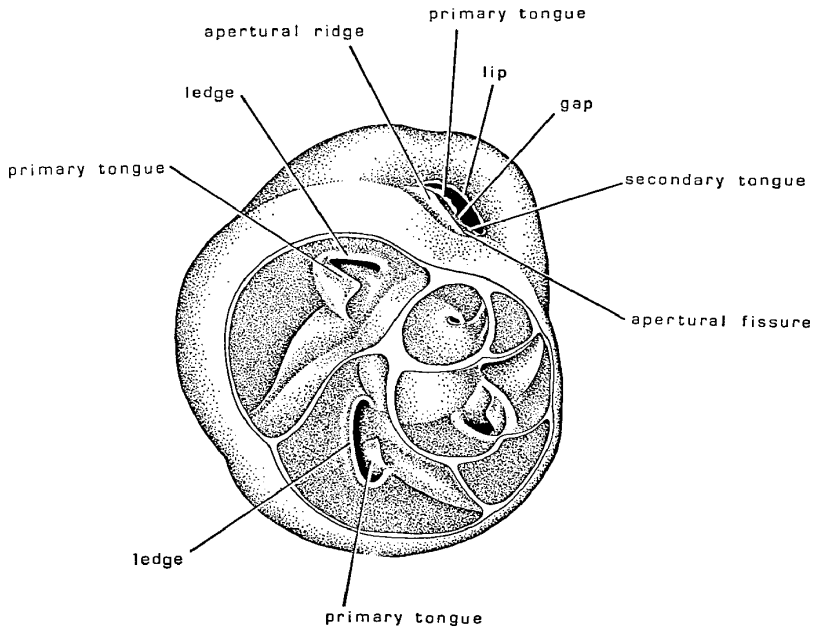


Fig. 22. Inner structure of *Islandiella islandica* (Nørvang).

Islandiella compressa Nomura, sp. nov.

Pl. 1, figs. 1a–c

Description: – Test medium, strongly compressed, nearly circular in side view; periphery compressed-rounded, not lobulate; chambers alternating biserially, quadrate in outline, not inflated; sutures distinct, radial, not depressed, very slightly curved toward periphery; umbilical region flat, filled with small, more hyaline shell material, showing a small part of earlier chambers; aperture short slit-shaped at the base of last-formed apertural face, almost parallel to periphery, showing indistinctly developed primary tongue; wall smooth, polished, very finely perforate, translucent.

Polarizing microscopy: – In polarized light, wall showing distinctly radial texture with a extinct cross similar to the typical uniaxial interference figure.

SEM observation: – Test microtopography smooth, and covered with calcitic microgranules. Pores rounded to oval and evenly distributed; apertural face and

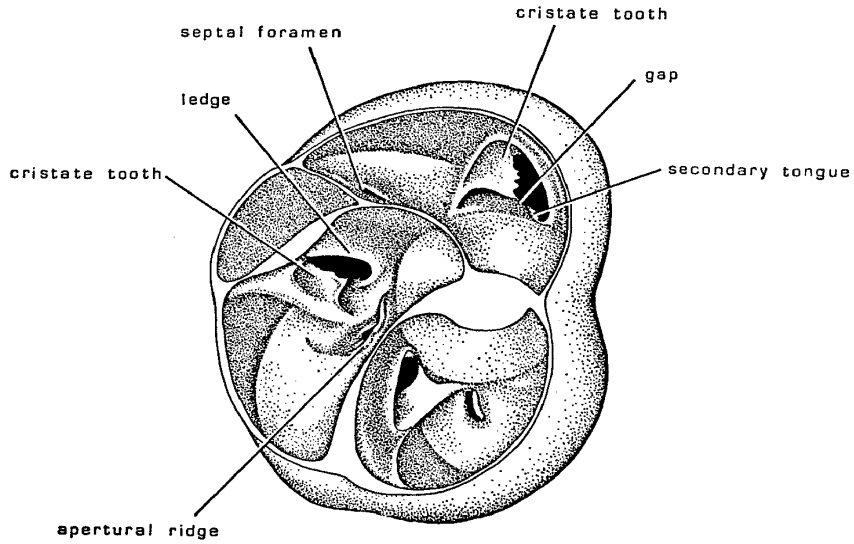


Fig. 23. Inner structure of *Islandiella islandica* (Nørvang).

sutures imperforate; average pore diameter 0.3 μm; pore density not determined. B1 Type aperture composed of primary and secondary tongues, lip, and apertural ridge; proximal end of primary tongue reaching the preceding septal foramen; anterior septal chamber wall attaching to previous coil and its free edge building up secondary tongue. Etched and fractured wall section showing II(B) Type wall structure.

Type and occurrence: – Holotype, Pl. 1, figs. 1a-c, IGPS 97167, ST–2, Hanaishi Conglomerate Member, Setana Formation, Hokkaido.

Remarks: – This new species has been found rarely in samples from Pleistocene deposits of the Japan Sea borderland.

A discoidal test and II Type wall structure indicate that this species is distinct from any other species belonging to the genus *Islandiella*.

In the general test shape, this species apparently resembles *Globocassidulina depressa* (Asano and Nakamura), but the former differs from the latter in its non-inflated chambers, umbilical region covered with clear shell material, and in having aperture of B Type.

The specific name refers to the shape of test.

Ontogeny and measurements:

IGPS	Sample	Length	Width	Thickness
97167 (Holotype)	ST–2	0 38 mm	0.32 mm	0.15 mm

Occurrence in studied area: – Found in samples KR–1; ST–1, 2, 7, 9, 11; NA–1.

Genus *Cassidulinoides* Cushman, 1927

Cassidulinoides Cushman, 1927b, p. 84.

Type species: – *Cassidulina parkeriana* Brady, 1881, p. 59; Brady, 1884, p. 432, pl. 54, figs. 11–16: Recent, Challenger station 304, 305, 308.

Diagnosis: – Test free, elongate, crosier-shaped in outline; periphery rounded; chambers uncoiled, but biserially arranged throughout and overlapped at periphery; sutures more or less depressed; wall calcareous, perforate, optically radial in texture; aperture subterminal to terminal, loop-shaped to oval, extending upward from the base of apertural face, with or without toothplate.

Stratigraphic distribution: – Pleistocene to Recent.

Remarks: – This genus was originally designated by Cushman in 1927 as follows:

"Test in the early stages like *Cassidulina* but in the adult becoming uncoiled in a series of alternating chambers, aperture terminal." Since the Cushman's designation, many species with these characters have been included in this genus. However, as revealed by Wood (1949), *Cassidulinoides parkerianus*, the type species of this genus, has a radial wall texture. Later Loeblich and Tappan (1964a) restricted this genus to include only elongate forms with a radial wall texture and toothplate. On the other hand, Eade (1967) proposed *Evolvocassidulina*, which has a *Cassidulinoides*-like chamber arrangement, but possesses a distinct granular wall texture. Loeblich and Tappan considered that the wall structure and toothplate are valid for generic distinction. As clarified in other genera treated in this study, however, the toothplate is very variable in shape among different species. The taxonomic significance of the toothplate is, therefore, specific rather than generic in importance.

Cassidulinoides somewhat resembles *Hastilina* gen nov., giving somewhat deviant appearance from normal cassiduline forms, but characteristically differs from the latter in having non-fusiform test and non-embraced chamber.

The stratigraphic range of this genus is unknown at present. Many species previously included in this genus are conceivably referable to *Evolvocassidulina*, although their wall structure has not been clarified as yet. So far as the present study is concerned, this genus ranges at least from the Pleistocene to Recent.

Cassidulinoides subcylindricus Nomura, sp. nov.

Pl. 1, figs. 4a–c; Pl. 7, figs. 6–10

Description: – Test rather small, ellipsoid, slightly compressed, broadly oval in cross section; periphery rounded, slightly lobulate; chambers distinct, oval in outline, slightly inflated, about four pairs visible in adult, closely coiled in early portion, later in uncoiled biserial arrangement, and overlapping, last-formed pair comprising about a half of entire test; sutures distinct, moderately curved, slightly depressed; aperture large, subterminal, a rounded foramen at the center of last-formed apertural face, provided with bordered lip; wall very thin, transparent, smooth and polished, very finely perforate.

Polarizing microscopy: – In polarized light, fragments in Lakeside cement revealing permanent extinction in the center of wall, indicating distinctly radial texture.

SEM observation: – Test microtopography smooth; calcitic microgranules on test surface not ascertained due to result of natural corrosion (Pl. 7, figs. 9, 10). Pores fine and evenly distributed; pores mostly rounded, but rarely elongate (Pl. 7, fig. 10); average pore diameter 0.8 μm; pore density 36 pores per $20 \times 20\ \mu m^2$. Inner structure showing oval aperture formed by coalition of lip and lip-like cristate tooth (Pl. 7, fig. 7); copula without primary tongue being glued to preceding septal chamber wall, but its proximal end not reaching preceding foramen. Fractured wall section showing needle-shaped crystal elements running normal to inner and outer test surfaces.

Type and occurrence: – Holotype, Pl. 1, figs. 4a-c, IGPS 97182A, sample AR-6, Tanihama Formation, Niigata Prefecture.

Remarks: – Although the occurrence of this species from the Pleistocene of the Japan Sea borderland is rather limited, this species is clearly different from all other known species of the genus. Diagnostic features of this species are its ellipsoidal test and oval aperture without toothplate.

In the apertural character and coiling type, this species differs from *Cassidulinoides parkerianus* (Brady) in loosely coiled early portion (type D) and absence of toothplate.

Cassidulinoides subcylindricus is somewhat similar to *Virgulina makiyamae* Chiji (1961), but differs from the latter in having a test not showing its proloculus, low and broad chambers, and oval aperture. From *Hastilina cornuta* (Cushman), this species is differentiated in having distinctly radial texture, different apertural shape, and coiling type.

In the test shape, this species apparently resembles *Evolvocassidulina kuwanoi* (Matoba), but it is easily distinguishable from the latter in its aperture having a larger foramen, distinctly radial texture, and larger test.

Ontogeny and measurements: – Ontogenetic variation slight.

IGPS	Sample	Length	Width	Thickness
97182A (Holotype)	AR–6	0.27 mm	0.18 mm	0.17 mm
97182B (Paratype)	–	0.27	0.17	0.17

Occurrence in studied area: – Found only rarely in samples OG–3, 13, 18; AR–6. This species may be restricted to the Japan Sea borderland.

Genus *Takayanagia* Nomura, gen nov.

Type species: – *Cassidulina delicata* Cushman, 1927d, p. 168, pl. 6, fig. 5: Recent, Lydonia Station 30 (22), off Panama, Pacific Ocean.

Diagnosis: – Test free, compressed, lenticular in outline; periphery subacute to carinate; chambers broad, curved, usually four pairs making up last formed coil, biserially arranged, and having chambers of opposite side visible as a small triangular intercameral areas along periphery; sutures curved; umbilicus closed; wall calcareous, hyaline, perforate, optically radial in texture; surface smooth and polished; aperture interiomarginal, a long and narrow slit along periphery of preceding chamber, with very small apertural ridge.

Stratigraphic distribution: – Lower Pliocene to Recent.

Remarks: – At present, the genus *Takayanagia* is monospecific. Although this new genus is similar to *Paracassidulina*, both in external and internal test shapes as well as in its apertural character, *Takayanagia* is clearly distinguished by having a distinctly radial wall texture. The co-existence of both forms having optically granular and radial walls has been demonstrated by some workers in such genera as *Elphidium*, *Turrilina*, and *Cassidulina* (Wood, 1949; Buzas, 1966; Hansen, 1972a; Haynes, 1973; Hansen and Lykke-Andersen, 1976). These authors considered that the optical character of wall, namely, granular and radial wall texture is significant only at the specific level. However, the present writer believes this difference in wall textures to be of generic rather than specific significance as discussed in other part of this paper.

It is difficult to detect the evolutionary lineage of *Takayanagia*, since no significant change in apertural morphology occurs during the ontogeny of this species. In having a radial wall texture, this genus appears to be related to *Islandiella*, and may have been derived from it. The present writer is, however, inclined to consider that *Takayanagia* has derived from *Paracassidulina* by changing the texture from granular to radial.

The oldest geologic occurrence is in the early Pliocene of Ventura County, California, reported by R.E. and K.C. Stewart (1930). In Japan, this genus has been reported from Pliocene to Recent sediments on the Pacific side under the genus *Cassidulina*.

The generic name is given in honor of Prof. Yokichi Takayanagi of the Institute of Geology and Paleontology, Tohoku University, who introduced the present writer to the study of foraminiferal classification.

Takayanagia delicata (Cushman), 1927

Pl. 1, figs. 3a–c; Pl. 7, figs. 1–5

Cassidulina delicata Cushman, 1927d, p. 168, pl. 6, fig. 5; Cushman and Moyer, 1930, p. 61, pl. 8, fig. 16; Cushman, 1934, p. 132, pl. 16, fig. 12; Cushman, 1941a, p. 38, pl. 9, fig. 22; Cushman and Todd, 1945, p. 62, pl. 10, fig. 12; Crouch, 1952, p. 838, pl. 6, fig. 7; Bandy, 1953, pl. 25, figs. 4a-c; Walton, 1955, p. 1004, pl. 103, figs. 28, 29; Uchio, 1960, p. 68, pl. 9, fig. 17; Ishiwada, 1964, p. 42, pl. 7, fig. 95; Matoba, 1967, p. 252, pl. 28, figs. 7a, b.

Cassidulina delicatula Cushman, 1929, p. 101, pl. 14, figs. 12a, b.

Cassidulina cushmani R.E. and K.C. Stewart, 1930, p. 71, pl. 9, figs. 5a, b; Douglas, 1973, p. 632, 633, pl. 6, fig. 6.

Cassidulina asanoi Uchio, 1950, p. 190, fig. 13; Uchio, 1951, p. 39, 40, pl. 3, figs. 2a, b; Asano, 1951, pt. 7, p. 2, text-figs. 1, 2; LeRoy, 1964, p. F40, pl. 11, fig. 29.

Cassidulina sp. cf. *delicata* Cushman. Becker and Dusenbury, 1958, p. 41, 42, pl. 4, figs. 28a–c.

Not *Cassidulina delicata* Cushman. Chapman, Parr, and Collins, 1934, p. 560, pl. 10, figs. 27a–c; Renz, 1948, p. 125, pl. 9, figs. 10a, b; Cushman, Todd, and Post, 1954, p. 365, 366, pl. 9, fig. 25; Todd, 1957b, pl. 77, fig. 6; Belford, 1966, p. 140, 142, pl. 24, figs. 5–10, text-fig. 16, nos. 3, 4; Zheng, 1979, p. 188, pl. 25, figs. 1a–c.

Not *Cassidulina asanoi* Uchio. Kikuchi, 1964, pl. 7, figs. 12, 13.

Description: – Test medium, nearly circular in side view, lenticular in edge view; periphery acute, thinly carinate, not lobulate; chambers broad and elongate, somewhat sublunate, very slightly inflated, four pairs making up last coil, uniformly increasing in size as added, so that a set of overlapping triangular portion very small at periphery; sutures somewhat distinct, radially much curved toward periphery; umbilical region closed; aperture long narrow slit, parallel to periphery of preceding chamber; wall very thin, finely perforate, smooth and polished.

Polarizing microscopy: – In transmitted light, tangential section showing many tiny pores perpendicular to surface. In polarized light, undulatory extinction occurring. Fragments in Lakeside cement showing distinctly radial texture.

SEM observation: – Test microtopography smooth; high magnification revealing calcitic microgranules on test surface. Pores rounded, evenly distributed, but absent in carina, sutures, and septal chamber walls; on earlier chambers pores very slightly depressed (Pl. 7, fig. 5) and somewhat larger near umbilical area than in peripheral portion; pore diameter 0.2–1.7 μm; pore density 7 pores per 20×20 μm^2. Inner structure viewed in anatomy showing no toothplate (Figs. 24, 25); interiomarginal slit-shaped aperture formed by infolding of septal chamber wall; apertural ledge attaching to preceding septal chamber wall at posterior end, and to earlier-formed chamber wall without secondary tongue at anterior end; apertural ridge formed at anterior periphery of preceding chamber wall, and thinly protruded; pseudolip not formed. Etched wall section revealing I Type structure.

Type and occurrence: – Homoeotype, Pl. 1, figs. 3a-c, IGPS 97184, sample BS–16, Kokumoto Formation, Boso Peninsula.

Remarks: – The present specimens referred to *T. delicata* are principally characterized by an elongate narrow slit-shaped interiomarginal aperture with an apertural ridge (G2 Type), and I Type wall structure (distinctly radial texture).

In his designation of this species, Cushman (1927d) illustrated the holotype with a widely spread aperture and protruded apertural face. However, the later published figures of this species as identified by many authors are characterized by a circular test, much curved sutures, and four paired chambers. According to Uchio (1960), Cushman's original figure is not representative of this species. Judging also from Uchio's description, there seems to be no definite criteria to separate *C. asanoi* from *T. delicata*. Therefore, *C. asanoi* is here

placed in the synonymy of *T. delicata* in agreement with the conclusion of both Ishiwada (1964) and Matoba (1967).

As pointed out by Crouch (1952), Uchio (1960), and Feyling-Hanssen and Buzas (1976, p. 155), a Californian species, *C. cushmani*, is another closely allied form. At the time of their proposal of *C. cushmani*, R.E. Stewart and K.C. Stewart (1930) recognized some distinction from "*C*". *delicata*. On the contrary, Feyling-Hanssen and Buzas (*op. cit.*) stated that "*C. asanoi*, *C. cushmani*, and *C. delicata* are all optically radial, and are compressed and have a long narrow slit for an aperture sometimes containing a plate-like lip (=apertural ridge in this paper)." The microspheric form of *T. delicata* from the Pliocene Yonabaru Formation shows a considerable resemblance to the type figures of *C. cushmani*. Furthermore, the sharpness of the periphery of *T. delicata* simply depends on the thickness of test, and a wide variation occurs among examined specimens of *T. delicata*. Taking these features into consideration, the present writer agrees with the determination of Crouch (1952) and Uchio (1960). Thus, the three species are believed to be lumped together as a single species, *T. delicata*.

Some figures of *T. delicata* by previous workers show apertural grooves. Since the aperture of *T. delicata* does not possess the apertural grooves, they are clearly identified with *Paracassidulina sulcata* Belford (1966).

Ontogeny and measurements: – Ontogenetic variation not so distinct; younger forms having a narrowly rounded periphery in earlier parts of the test.

IGPS	Sample	Length	Width	Thickness
97184–1	BS–6	0.12 mm	0.11 mm	0.77 mm
97184–2	–	0.13	0.11	0.08
97184–3	–	0.15	0.13	0.09
97184–4	–	0.17	0.15	0.10
97184–5	–	0.18	0.16	0.10
97184–6	–	0.21	0.17	0.12
97184–7	–	0.25	0.22	0.13

Occurrence in studied area: – Found in samples OG–18; CH–8; BS–12, 15, 16; OK–2.

Previous record of occurrence: – Most of the previous records from Miocene to Recent sediments of the Pacific side as follows: Recent, off Panama (Cushman, 1927d); Recent, off California (Cushman, 1934; Crouch, 1952; Bandy, 1953; Walton, 1955; Uchio, 1960); Recent, off Pacific coast of Japan (Ishiwada, 1964); Pliocene,

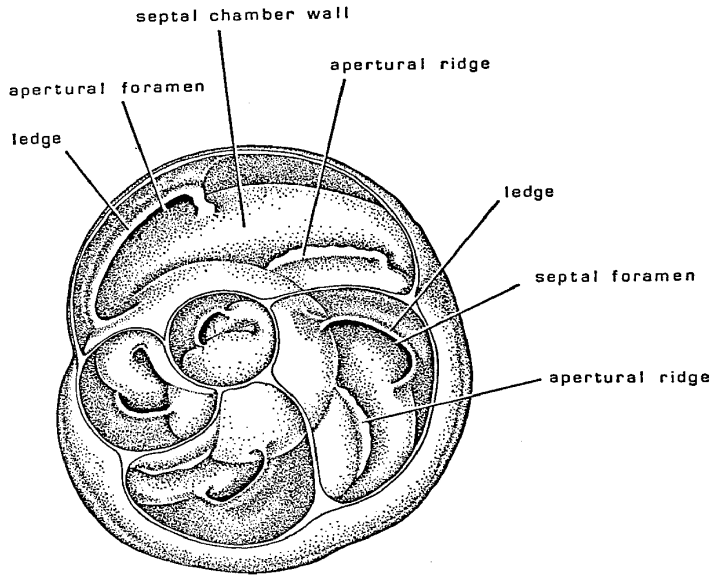


Fig. 24. Inner structure of *Takayanagia delicata* (Cushman), gen. nov.

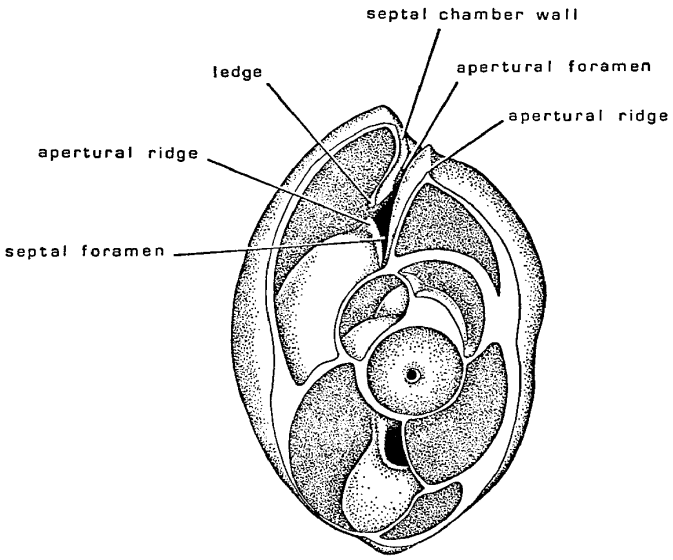


Fig. 25. Inner structure of *Takayanagia delicata* (Cushman), gen. nov.

Ventura County, California (R.E. and K.C. Stewart, 1930); Viti Levu, Fiji (Cushman, 1934); Miocene, Buff Bay, Jamaica (Cushman and Todd, 1945); Pleistocene, Kokumoto Formation, Boso Peninsula, Japan (Uchio, 1951); Pliocene, Yonabaru and Shinzato Formations, Okinawa Island, Japan (LeRoy, 1964); Pleistocene, Choshi district, Chiba Prefecture, Japan (Matoba, 1967).

Genus *Globocassidulina* Voloshinova, 1960

Globocassidulina Voloshinova, 1960, p. 58.
Cassilongina Voloshinova, 1960, p. 58 (type, *Cassidulina oblonga* Reuss, 1850).
Smyrnella Saidova, 1975, p. 331, 332 (type, *Cassidulina subglobosa* Brady var. *subcalifornica* Drooger, 1953).
Cassidulinitella Saidova, 1975, p. 329, 330 (type, *Cassidulinitella salebrosa* Saidova, 1975).
Cassisphaerina Saidova, 1975, p. 336, 337 (type, *Cassisphaerina globula* Saidova, 1975).
Bradynella Saidova, 1975, p. 344, 345 (type, *Cassidulina subglobosa* Brady, 1881).
Sphaeroislandiella Saidova, 1975, p. 342 (type, *Sphaeroislandiella notalnella* Saidova, 1975).

Type species: – *Cassidulina globosa* Hantken, 1875, p. 64, pl. 16, figs. 2a, b: Lower Oligocene, Hungary.

Diagnosis: – Test free, lenticular to globular in outline; periphery rounded to subacute, or carinate; chambers broad to elongate, biserially arranged and enrolled, with a set of short and tapering end at periphery; sutures curved to straight, almost radially arranged, but sometimes tangentially arranged; umbilicus commonly closed; wall calcareous, optically granular in texture, perforated with round to slit shape; aperture oval, slit-shaped or tripartite, commonly extending up at a high angle to apertural face of final chamber, with toothplate on posterior side and indistinct secondary tongue on anterior side; surface smooth and polished, or decorated with reticulate costae, and/or covered with numerous small papillae.

Stratigraphic distribution: – Upper Eocene to Recent.

Remarks: – *Cassidulina globosa* Hantken (1875) was designated as the type species of the genus *Globocassidulina* by Voloshinova (1960). She also proposed the genus *Cassilongina* based upon *Cassidulina oblonga* Reuss (1850). But this genus has been regarded as a synonymy of *Globocassidulina* by later workers, including Voloshinova herself (Voloshinova *et al.*, 1970). As pointed out by Loeblich and Tappan (1964a), *Cassidulina oblonga*

has an elongate test, but does not display uncoiling. Nørvang (1958) considered that *C. globosa* is synonymous with *C. oblonga*.

The redefinition of this genus given by Loeblich and Tappan (1964a, p. C738) is "Test...., subglobular, ... aperture a narrow slit extending up face of final chamber, may have narrow infolded rim, but no apertural tooth." On the other hand, lens-shaped species here included in *Globocassidulina* have been confused in the past with *Cassidulina* which has a typically lenticular morphology, but a characteristic difference between them is in the shape of aperture. In *Globocassidulina* (s.s.) three types of apertural shapes are recognized, namely, oval (C Type), erected loop (D Type), and tripartite (E Type) with or without externally protruded cristate tooth and internally separated primary tongue.

These apertural types also appear to reflect different stages in ontogenetic development. Eade (1967) considered a tripartite aperture to be variable, and stated as follows: "one or two of these branches are usually reduced in the adult." But the tripartite aperture appears only in the adult stage, and the variation of branches, particularly basal branch, is observed in the adult stage. Species with the tripartite aperture in their juvenile stage appear to have only an areal branch (D Type).

At the time of erection of several cassiduline genera, some confusion has been caused by Saidova (1975) in interpreting apertural characters and wall texture. With regard to these characters and test shape, she gave a following diagnosis of each genus: *Smyrnella* has a ball-shaped to flattened test, aperture of D Type, and granular wall texture; *Cassidulinitella* has a disc-shaped test, aperture of D Type, and granular wall texture; *Cassisphaerina* has a ball-shaped test, aperture of curved slit perpendicular to apertural face, and granular wall texture; *Bradynella* has a spherical test, aperture of D Type, and radial wall texture; *Sphaeroislandiella* has a ball-shaped, aperture of D Type, and radial wall texture. However, it is difficult to accept such generic distinctions based principally on apertural features, because, as stated above, the development of basal and areal apertural branches is ontogenetically variable. On the wall texture opinions were divided: Saidova (*op. cit.*) and Troitskaja (1970) described *"Cassidulina" subglobosa* Brady as possessing a radial wall texture, whereas Belford (1966), who investigated the topotype of "Challenger" station, stated that *"C" subglobosa* have a granular wall texture. Furthermore, Saidova (1975) stated that *"Cassidulina" gemma* Todd has a radial wall texture, while Belford thought that the wall of *G. gemma* is of granular texture. So far as the present writer's examination indicates, wall of both species is clearly granular in texture, although a question is raised on the validity of genera with radially built texture such as *Bradynella* (type species *"C" subglobosa*) and *Sphaeroislandiella* (including *"C" gemma*).

At present, it is very difficult to estimate the derivation of the genus *Globocassidulina* on the basis of apertural character and the mode of chamber arrangement. In any case, the *Globocassidulina* lineage may have begun in the late Eocene. In Japan, *Globocassidulina globosa* (Hantken) was reported by Asano (1952a) from the Paleogene Poronai Formation in Hokkaido.

Globocassidulina parviapertura Nomura sp. nov.

Pl. 1, figs. 6a, b; Pl. 12, figs. 5–8

Description: – Test large to medium, stout, subcircular in side view, nearly quadrangular in apertural view, slightly longer than broad; periphery broadly rounded, not lobulate; chambers distinct, not inflated, four pairs making up last formed coil, biserially arranged and

involutely coiled, overlapping at periphery; sutures distinct, narrowly limbate, not depressed; aperture very small, narrowly elongate, at right angles to suture of apertural face, nearly on a plane of coiling, usually with small fragile cristate tooth extending from one side of foramen; wall rather thick, smooth, polished, very finely perforate, semi-opaque.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth, showing irregular shaped calcitic microgranules (Pl. 12, fig. 8). Pores on earlier portion typically slit-shaped (Pl. 12, fig. 8) and rounded on final chamber; poorly developed apertural face imperforate; length of slit-type pore 0.4 μm; pore density 14 pores per $20\times20\ \mu m^2$. Aperture D6 Type; somewhat protruded cristate tooth visible on posterior side (Pl. 12, fig. 5); primary tongue not formed; proximal end of copula attaching to preceding apertural face (Pl. 12, fig. 6); cristate tooth much reduced in early ontogenetic stages, and only recognized as a thickened rim (Pl. 12, fig. 7); lip indistinct. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 6a, b, IGPS 97187, sample OK–18, upper Yonabaru Formation, Okinawa Island; paratype, IGPS 97187–5, the same sample.

Remarks: – A squash form of the test in an apertural view non-lobulate periphery, slit-type pores, and very small aperture with a cristate tooth are all diagnostic features of this species. The ratio of the maximum length of the aperture to that of the test is about eight to nine.

This species is very close to *Globocassidulina pseudoquadrata* sp. nov. in its quadrate test shape, but is easily distinguished from the latter in apertural characters and pore shapes.

Islandiella quadrata (=*Cassidulina subglobosa* Brady var. *quadrata* Cushman and Hughes) seemingly resembles this new species. According to Nørvang (1958, p. 32), and Feyling-Hanssen and Buzas (1976), however, *I. quadrata* has a radial wall texture.

The prefix "*parvi-*" is from the Latin *parvus* meaning small or short with reference to the character of the aperture.

Ontogeny and measurements: – Ontogenetical developments are shown in Figure 26. Juvenile forms subglobular in shape similar to *G. subglobosa*.

Ontogeny and measurement:

IGPS	Sample	Length	Width	Thickness	Fig. 26
97187–1	OK–18	0.24 mm	0.20 mm	0.20 mm	(1)
97187–2	–	0.32	0.27	0.20	(2)
97187–3	–	0.35	0.34	0.29	(3)
97187–4	–	0.35	0.34	0.29	(4)
97187–5 (Paratype)	–	0.40	0.35	0.34	(5)
97187 (Holotype)	–	0.65	0.59	0.56	(6)

Occurrence in studied area: – Found only in samples OK–5, 8, 10(A), 14, 18 from the Yonabaru Formation.

Globocassidulina ryukyuensis Nomura, sp. nov.

Pl. 1, figs. 5a–c: Pl. 22, figs. 2–6

Description: – Test large, slightly longer than broad, oval to rounded-rectangular in peripheral view, nearly circular in cross section; periphery broadly rounded, not lobulate; chambers distinct except for earlier portion, low and broad, not inflated, gradually increasing in size as added, but rapidly decreasing its size in last pair; biserial series of chambers closely coiled in early stage but slightly prolonged in last stage, overlapping less than half their length in rounded peripheral margin, about five to six pairs making up last-formed coil; sutures distinct except for

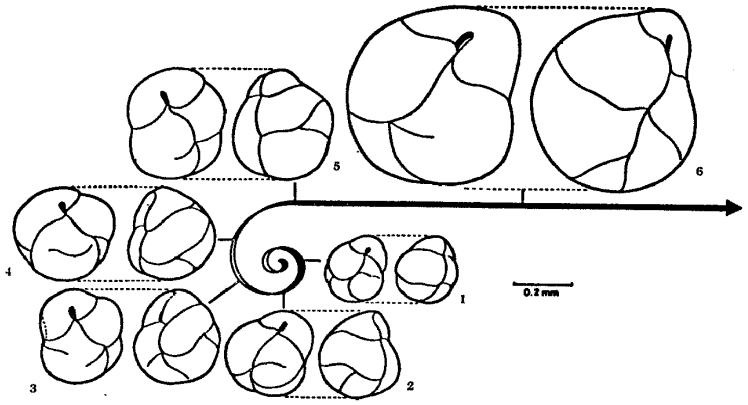


Fig. 26. Ontogeny of *Globocassidulina parviapertura* Nomura, sp. nov.

early portion, gently curved, very narrowly limbate in later, not depressed; aperture small for test, terminal, short narrow slit oblique to a plane of coiling, situated in middle part of poorly developed apertural face, provided with thin transparent raised lip; wall initially thin and later thickened and opaque.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography varying from smooth on later chambers to very slightly rugged on earlier chambers (Pl. 22, fig. 6), but almost occupied by smooth and calcitic microgranules. Pores on earlier chambers slit-shaped, but small and rounded on final and penultimate chambers; average length of slit-type pore 1.1 μm; pore density 24 pores per $20 \times 20\ \mu m^2$. Aperture D7 Type, bounded by externally protruded lip and cristate tooth; inner structure (Pl. 22, figs. 2, 3, 4, 5; Fig. 28) showing primary tongue internally separated from copula and cavity under primary tongue; proximal end of copula attaching obliquely to basal part of preceding apertural face (Pl. 22, figs. 4, 5); secondary tongue very poorly developed, and not protruded externally; gap formed in matured stages, but absent in immature stages (Pl. 22, fig. 5). Etched wall showing III-Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 5a-c, IGPS 97190A, sample OK–1, middle Yonabaru Formation, Okinawa Island; paratype 97190B, the same sample.

Remarks: – Two forms of this species may be recognized on their external appearance; one is egg-shaped, the other is rounded rectangular. The specimen which has an egg-shaped test, small aperture, and non-lobulate periphery is allied to *Burseolina pacifica* (Cushman) in its shape of test and chamber arrangement, but differs from the latter in its apertural shape. Neverthelss, the test shape in earlier ontogeny and growth pattern of toothplate are very similar in both species, and these features suggest a close relationship between the two. Because of the aperture without distinct apertural flap, the present new species is placed in *Globocassidulina*. An early ephebic stage of this species somewhat resembles *G. parviapertura*, but is distinguished from the latter in having a more spherical test, non-lobulate periphery, primary tongue, and not having the cristate tooth.

Globocassidulina spherica Eade also resembles this new species but differs in its apertural structure. The original illustration of the inner structure of *G. spherica* shows that the distal end of the secondary tongue does not adhere to the primary tongue or copula. On the other hand, the same distal end of *G. ryukyuensis* adheres to the middle portion of

copula, so that the aperture displays a small subterminal foramen.

The specific name is taken from the Ryukyu Islands.

Ontogeny and measurement: – In early ephebic stages this species very similar to *G. subglobosa* (Fig. 27).

IGPS	Sample	Length	Width	Thickness	Fig. 27
97190–1	OK–1	0.19 mm	0.19 mm	0.18 mm	(1)
97190–2	–	0.25	0.22	0.19	(2)
97190–3	–	0.26	0.22	0.21	(3)
97190–4	–	0.25	0.22	0.21	(4)
97190–5	–	0.29	0.27	0.30	(5)
97190–6	–	0.37	0.29	0.29	(6)
97190–7	–	0.36	0.30	0.30	(7)
97190–8	–	0.40	0.35	0.32	(8)
97190–9	–	0.43	0.35	0.34	(9)
97190–10	–	0.48	0.36	0.35	(10)
97190–11	–	0.51	0.40	0.38	(11)
97190A (Holotype)	–	0.57	0.42	0.42	
97190B (Paratype)	–	0.57	0.42	0.39	

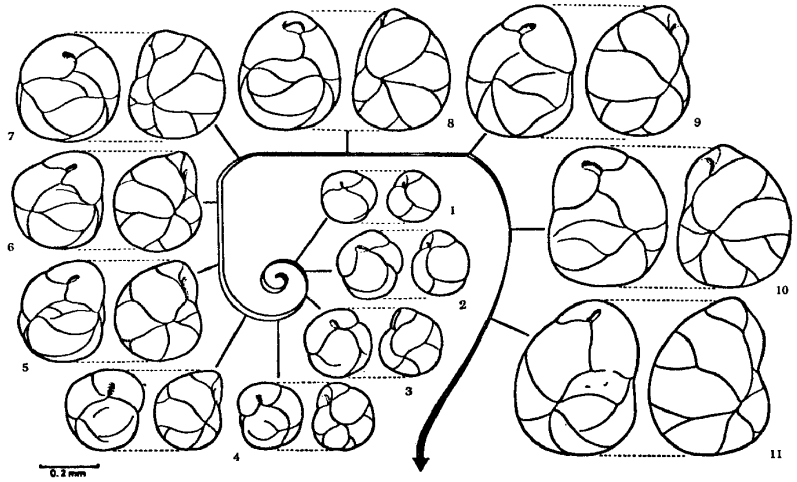


Fig. 27. Ontogeny of *Globocassidulina ryukyuensis* Nomura, sp. nov.

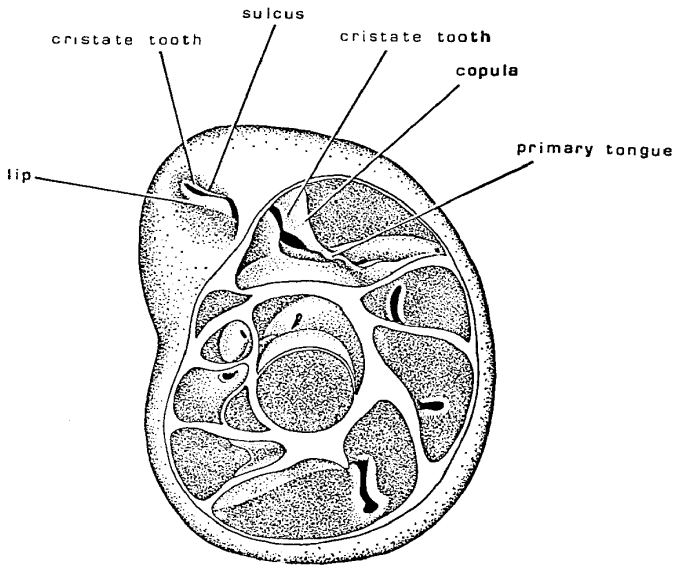


Fig. 28. Inner structure of *Globocassidulina ryukyuensis* Nomura sp. nov.

Occurrence in studied area: – Found abundantly only in samples OK–1 and 3.

Globocassidulina venustas Nomura, sp. nov.

Pl. 1, figs. 7a–c, 8: Pl. 14, figs. 4–7

Description: – Test very small, compressed, nearly circular in side view, lenticular in edge view; periphery acute to subacute, slightly or strongly lobulate, particularly in later portion; chambers distinct except for umbilical region, wedge-shaped to subtrapezoidal, not inflated, not reaching umbilicus on both side, about five to six pairs in last coil; umbilical region polished, perforate, semi-opaque; sutures distinct, narrowly limbate, not depressed, nearly straight; aperture short narrow slit, extending from the base of poorly developed apertural face, nearly parallel to a plane of coiling; wall smooth, finely perforate, translucent to semi-opaque.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth; calcitic microgranules wholly covering test surface. Pores almost irregular and elongate (Pl. 14, fig. 7); on final chamber, pores small and sporadically distributed; pore size 0.3 to 2.0 μm; pore density seven pores per 20×20 μm^2. Aperture D Type; inner structure somewhat similar to that of *I. norcrossi* (Pl. 14, figs. 4, 5, 6; Fig. 29), but primary tongue not formed, and only composed of thickened copula on one side (Pl. 14, fig. 6); proximal end of copula not attached to preceding apertural face, or to adjacent previous coil (Pl. 14, fig. 4); cristate tooth much reduced and only vestigially recognized (Pl. 14, fig. 5); apertural ledge thickened (Pl. 14, fig. 5). Etched wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 7a-c, IGPS 97224, sample MU–1, Nojima Formation, Miura Peninsula; paratype, IGPS 97225, the same sample.

Remarks: – This new species is characterized by a small test and large numbers of chambers without typical biserial arrangement. These diagnostic features of *G. venustus* serve to distinguish it easily from other species of *Globocassidulina*. However, apertural characters and III Type wall structure suggest that this species is appropriate to be placed in the genus *Globocassidulina*. *Islandiella norcrossi* (Cushman) is somewhat similar to this one, but *G. venustas* is easily distinguishable from the former in its apertural shape, wall texture, and number of chambers per one whorl. This new species also resembles *Cassidulina norcrossi* Cushman subsp. *australis* Phleger and Parker in its test shape as seen from the side, but differs from the latter in its more evolute test, short chambers, and slightly lobulate and non-carinate periphery.

This species is named after the Latin *venustas* meaning beauty or charm, referring to the arrangement of chamber.

Ontogeny and measurements:

IGPS	Sample	Length	Width	Thickness
97224 (Holotype)	MU–1	0.22 mm	0.20 mm	0.07 mm
97225 (Paratype)	–	0.21	0.20	0.08

Occurrence in studied area: – Found rarely in samples BS–7 (A), 8, 13, 15; MU–1, 2, 4–6. This species is restricted to the Pacific side.

Globocassidulina crenulata Nomura, sp. nov.

Pl. 1, figs. 9a–c, 10a, b; Pl. 19, figs. 7–9, 11

Description: – Test medium, somewhat compressed, nearly circular in side view, lenticular in edge view, apertural face completely flattened; periphery with keel, distinctly serrated; chambers distinct, nearly rectangular in general shape, not inflated, three pairs in last coil, tangentially arranged, last-formed pair mak-

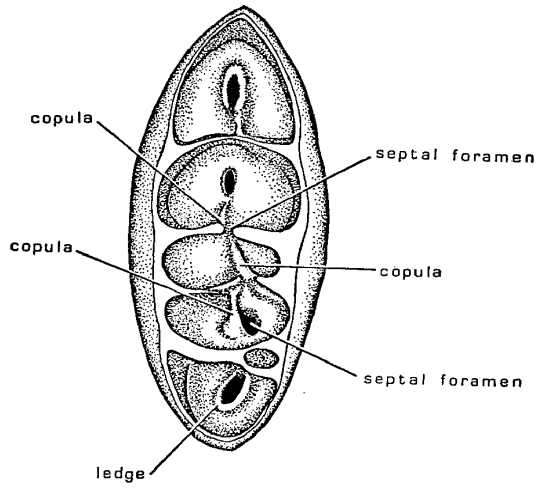


Fig. 29. Inner structure of *Globocassidulina venustas* Nomura, sp. nov.

ing up about a half of entire test, periphery of each chamber alternately depressed on one side so that zigzag-shaped in peripheral view; sutures distinct, gently curved, depressed near periphery, V-shaped sutural grooves visible at the base of last-formed apertural face; aperture L-shaped, surrounded by narrow depression; apertural grooves radiating in all directions of aperture, but not strongly developed; wall rugged, except for last-formed pair, so that diffused reflection given, very finely perforate, translucent. *Polarizing microscopy*: Wall jagged-granular texture.

SEM observation: – Test microtopography changing from smooth to rugged; on final and penultimate chambers smooth, whereas on earlier chambers rugged (Pl. 19, fig. 9); apertural grooves U-shaped in proximal part but wedge out toward periphery. Pores almost rounded to slightly elongate on smooth test surface, but irregular in shape on rugged test surface; on apertural face and carina pores not present; average pore diameter of rounded type 0.86 μm; size of irregular type approximately 1.2 μm; pore density 14 pores per 20×20 μm^2. Aperture E1 Type, surrounded by tube-like lip and cristate tooth; copula formed by infolding of posterior septal chamber wall, and its proximal end attaching to basal part of anterior septal chamber wall (Pl. 19, figs. 7, 8; Fig. 30); much reduced primary tongue with cavity separating from copula (Pl. 19, fig. 8); secondary tongue formed by inward bending of anterior septal chamber wall, and its free part not glued to distal end of primary tongue in later ontogenetical stages; in immature stages, aperture loop-shaped and perpendicular to the base of apertural face, and secondary tonge glued to distal end of primary tongue. Etched wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 9a-c, IGPS 97191A, sample OK–4, Shinzato Formation, Okinawa Island; paratype, IGPS 97191B, the same sample.

Remarks: – The present species, which is characterized by its lenticular test, distinctly serrated peripheral carina, and L-shaped aperture, is similar to *Cassidulina subtumida* Cushman, but differs from the latter in the possession of serrated peripheral carina. This carina is the most characteristic feature of this species.

This species is named after the crenulate shape of its periphery.

Ontogeny and measurements: – Loop-shaped aperture converting into L-shaped (tripartite) one through ontogeny.

IGPS	Sample	Length	Width	Thickness
97191B (Paratype)	OK–4	0.26 mm	0.20 mm	0.14 mm
97191A (Holotype)	–	0.28	0.24	0.15
97191–1	–	0.32	0.28	0.15

Occurrence in studied area: – Found rarely in samples BS–1; OK–1, 4, 9, 10(A), (B), 14, 19, 21.

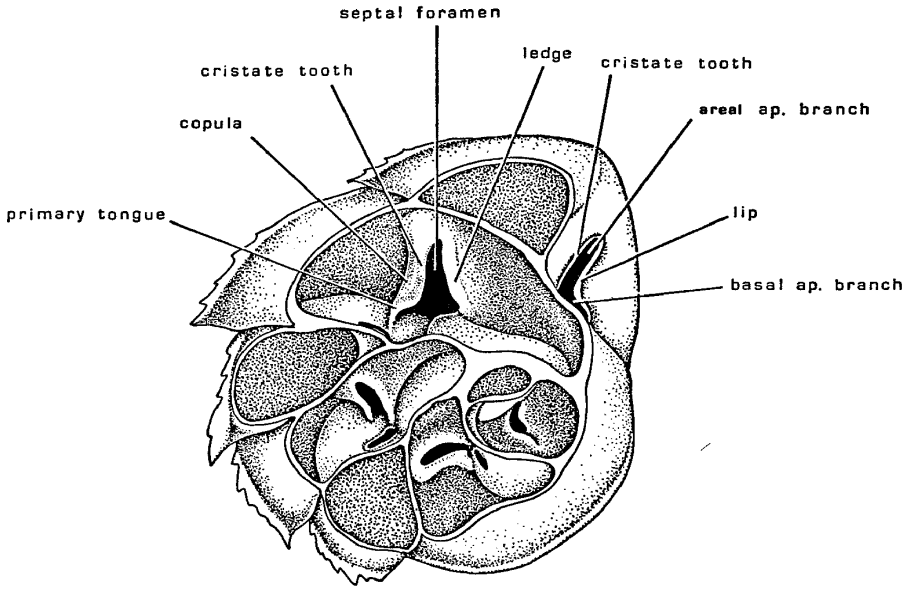


Fig. 30. Inner structure of *Globocassidulina crenulata* Nomura, sp. nov.

Globocassidulina pseudoquadrata Nomura, sp. nov.

Pl. 1, figs. 14a–c; Pl. 12, figs. 3, 4

Description: – Test medium, stout, last-formed chamber somewhat protruding, nearly quadrangular in apertural view; periphery broadly rounded, very slightly lobulate if at all; chambers distinct except for early portion, broadly oval, very slightly inflated, about four pairs in last-formed coil, succeedingly chambers much overlapped in peripheral view; sutures distinct except for earlier portion of test, very narrowly limbate, very slightly depressed, moderately curved; aperture elongate narrow slit extending up nearly at right angles to suture at the base of last-formed apertural face, oblique to a plane of coiling, surrounded by lip and lip-like cristate tooth; wall rather thick, earlier portion of test thickly calcified and interpore region convexly inflated so that diffuse reflection is given, finely perforate, translucent to semi-opaque.

Polarizing microscopy: – Test fragment showing jagged-granular texture.

SEM observation: – Test microtopography smooth, with depressed pores on earlier portion, and covered with calcitic micro-granules on test surface. Pores rounded and almost the same in size throughout; depressed pores restricted to earlier portion (Pl. 12, fig. 4), but becoming flush and evenly distributed toward later chambers; apertural face imperforate; pore diameter ranging from 0.7 to 2.0 μm; pore density four pores per $20 \times 20\ \mu m^2$. Aperture D Type, associated with slightly protruded lip-like cristate tooth on posterior side and lip on anterior side (Pl. 12, fig. 3); inner structure showing copula attached obliquely to proximal end of preceding lip, and fimbriate primary tongue separated from copula (Fig. 32); secondary tongue formed in previous chamber wall, but not connected with primary tongue; tips of both lip and cristate tooth somewhat dilated; apertural ridges formed in anterior periphery of preceding apertural face (Pl. 12, fig. 3). Wall structure III Type.

Type and occurrence: – Holotype, Pl. 1, figs. 14a-c, IGPS 97194A, sample OK–22, Shinzato Formation, Okinawa Island; paratype, IGPS, 97194B, the same sample.

Remarks: – This species is characterized by its quadrangular test shape, per-

pendicularly extended aperture, and rounded pores.

A thickly clacified early portion of the last whorl somewhat resembles *G. ornata* (Cushman) in an irregular reflection, but a mode of structure is quite different; *G. ornata* has reticulate costae, whereas *G. pseudoquadrata* has only inflated interpore regions. In the test shape, this new species closely resembles *Cassidulina subglobosa* Brady var. *quadrata* Cushman and Hughes (1925) (=*Islandiella quadrata*), but the former can be easily differentiated from the latter in its jagged-granular wall texture and *subglobosa*-like erect slit aperture.

From *Cassidulina vestae* Redmond, it differs in its larger test, more quadrate test, and indistinct sutures in its early portion. It is also closely resembles *G. parviapertura* sp. nov., but the former differs from the latter in apertural characters and pore shape.

This species is named after a quadrate shape of its test.

Ontogeny and measurements: – Ontogenetic variation slight; juvenile forms somewhat subglobular in comparison with the adult (Fig. 31).

IGPS	Sample	Length	Width	Thickness	Fig. 31
97194–1	OK–22	0.15 mm	0.12 mm	0.12 mm	(1)
97194–2	–	0.15	0.14	0.14	(2)
97194–3	–	0.17	0.15	0.14	(3)
97194B (Paratype)	–	0.20	0.18	0.16	(4)
97194–4	–	0.27	0.25	0.21	(5)
97194A (Holotype)	–	0.35	0.30	0.29	(6)

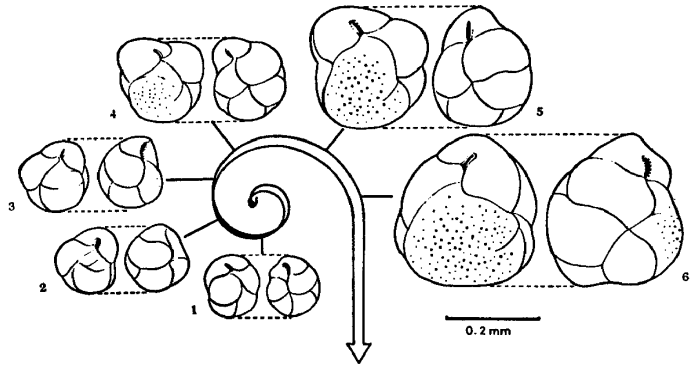


Fig. 31. Ontogeny of *Globocassidulina pseudoquadrata* Nomura, sp. nov.

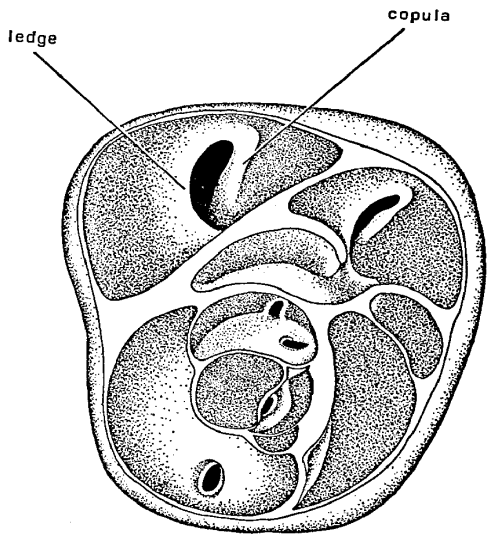


Fig. 32. Inner structure of *Globocassidulina pseudoquadrata* Nomura, sp. nov.

Occurrence in studied area: – Found in samples MU–7, 8; Ok–3, 20, 22.

Globocassidulina mucronata Nomura, sp. nov.

Pl. 1, figs. 12a–c, 13; Pl. 13, figs. 2–4

Description: – Test small, subglobular, slightly longer than broad; periphery broadly rounded, lobulate; chambers distinct, suboval, slightly inflated, four pairs making up last coil, gradually increasing in size as added, alternating

chambers overlapped at periphery; sutures distinct, moderately curved, gently depressed, not limbate; aperture short narrow slit, and nearly at right angles to suture at the base of apertural face, bordered by lip and lip-like cristate tooth; wall rather thick, rough, covered with numerous small lumps developing much in early portion so that diffusely reflected on surface, very finely perforate, but almost indistinct, semi-opaque.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography papillate on earlier portion of test, but less so toward newly formed chambers; microtopography of final chamber somewhat smooth without lumps (Pl. 13, figs. 2, 3, 4). Pores very small, rounded (approximately 0.3 μm), and indistinct throughout, but irregular-shaped pores (approximately 1.7 μm) also found; pore density 10 pores per $20 \times 20\ \mu m^2$. Aperture D Type; inner structure showing copula attached to anterior side of apertural face, and primary tongue not separated from copula; anterior end of septal chamber wall also attaching to basal part of preceding apertural face without secondary tongue; apertural ridge very poorly developed on previous chamber wall. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 12a-c, IGPS 97195A, sample OK–19, Shinzato Formation, Okinawa Island; paratype, IGPS 97195–7, the same sample.

Remarks: – This new species was found only in one sample from the Pliocene Shinzato Formation, although it occurs gregariously.

The diagnostic feature of this form is its subglobular test with the papillate surface (Pl. 13, figs. 3, 4).

In the test shape, size, and surface ornamentation, the new species is most closely allied to *G. undata* (Kuwano), but differs in sutures; *G. mucronata* has moderately curved sutures on the surface, whereas *G. undata* has undulate sutures.

The specific name refers to the rugged surface of its test.

Ontogeny and measurements: – Ontogenetic variation slight.

IGPS	Sample	Length	Width	Thickness
97195–1	OK–19	0.20 mm	0.17 mm	0.15 mm
97195–2	–	0.21	0.18	0.17
97195–3	–	0.23	0.20	0.17
97195–4	–	0.21	0.20	0.18
97195–5	–	0.25	0.23	0.20
97195–6	–	0.26	0.24	0.21
97195–7 (Paratype)	–	0.28	0.25	0.21
97195A (Holotype)	–	0.30	0.24	0.25

Occurrence in studied area: – Found only in sample OK–19.

Globocassidulina subparva Nomura, sp. nov.

Pl. 1, figs. 11a–c.

Description: – Test medium, subglobular; periphery broadly rounded, not lobulate; chambers distinct except for early portion, suboval, not inflated, four pairs in last-formed coil, gradually increasing in size as added, alternating chambers overlapped by about half the width in peripheral view; sutures distinct in later, very narrowly limbate, shallowly depressed, U- or V-shaped in section, moderately curved; aperture elongate narrow slit extending up about two-thirds last apertural face, orthogonally provided with a very short basal branch; wall rather thick, very finely perforate, surface smooth, polished, translucent to semi-opaque.

Polarizing microscopy: – Fragments of test

wall showing jagged-granular texture.

SEM observation: – Test microtopography smooth, with calcitic microgranules. Pores slit-shaped on earlier portion, but rounded on later chambers; slit-shaped pores arranged regularly toward aperture; apertural face imperforate; average length of slit-type 0.6 μm; pore density not determined. Aperture E Type, apparently close to D Type; inner structure showing copula formed by infolding of posterior septal chamber wall and attached to preceding septal foramen; narrow primary tongue separated from proximal part of copula; cristate tooth narrow and poorly developed; secondary tongue observed in adjacent previous whorl poorly developed. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 11a–c, IGPS 97197, sample OK–17, Yonabaru Formation, Okinawa Island; paratype, IGPS 97197–11, the same sample.

Remarks: – This new species has a L-shaped aperture with a very short basal apertural branch as its diagnostic feature.

The grooved sutures are restricted to the region of apertural side, and they gradually become not depressed away from the aperture. These features serve to distinguish it from other allied forms.

In test shape, this species is closely allied to *G. oriangulata* Belford (1966), but differs from the latter in its apertural features and mode of sutures. *G. subglobosa* also closely resembles this species, but can be readily separated from *G. subparva* by its distinctly developed erect aperture without the indication of tripartite feature and non-depressed sutures. *G. subparva* closely resembles *G. parva*, but differs in its less developed sutural grooves and in possessing the very short branch of basal aperture.

Ontogeny and measurements: – The shape of aperture varies ontogenetically. The basal apertural branch is absent in younger forms, and the shape of test somewhat resembles that of *G. subglobosa* (Fig. 33).

IGPS	Sample	Length	Width	Thickness	Fig. 33
97197–1	OK–17	0.14 mm	0.12 mm	0.12 mm	(1)
97197–2	–	0.17	0.15	0.15	(2)
97197–3	–	0.18	0.14	0.15	(3)
97197–4	–	0.23	0.20	0.19	(4)
97197–5	–	0.26	0.22	0.21	(5)
97197–6	–	0.29	0.24	0.23	(6)
97197–7	–	0.30	0.25	0.25	(7)
97197–8	–	0.32	0.29	0.25	(8)
97197–9	–	0.39	0.34	0.30	(9)
97197–10	–	0.42	0.37	0.32	(10)
97197–11 (Paratype)	–	0.45	0.39	0.32	(11)
97197 (Holotype)	–	0.42	0.37	0.32	

Occurrence in studied area: – Found only in samples OK–2, 3, 5, 7, 10 (B), 11, 14, 17, 19, 21, from Pliocene deposits of Okinawa Island.

Globocassidulina matobai Nomura, sp. nov.

Pl. 1, figs. 15a–c; Pl. 12, fig. 13

Description: – Test medium, subglobular, final chamber slightly projecting; periphery broadly rounded, very slightly lobulate; chambers distinct except for earlier portion, broadly oval, slightly inflated, about four pairs making up last coil, overlapping each other at periphery, very gradually increasing in size; sutures distinct, slightly depressed, not limbate, moderately curved; aperture elongate narrow slit, extended at right angles to periphery and situated in middle part of apertural face; apertural grooves

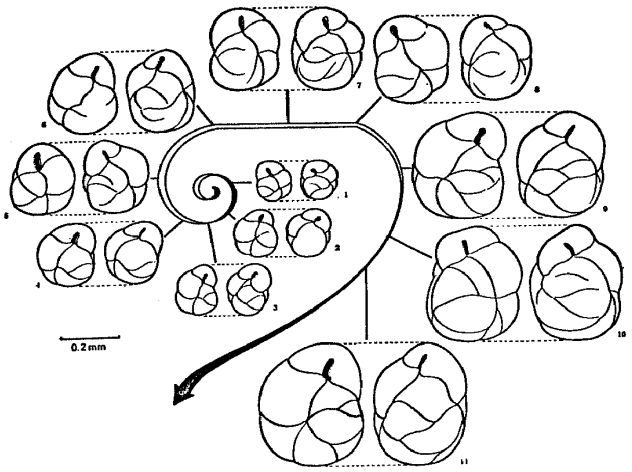


Fig. 33. Ontogeny of *Globocassidulina subparva* Nomura, sp. nov.

not so much developed, running out of aperture; wall smooth, polished, very finely perforate, semi-opaque.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth; calcitic microgranules covering test surface. Pores small, rounded, not depressed, and approximately the same in size throughout; average pore diameter 0.6 μm; pore density 13 pores per 20×20 μm^2. Aperture D3 Type; cristate tooth much reduced on posterior side; lip surrounding aperture on anterior side; inner structure showing primary tongue very poorly separated from copula; copula attaching obliquely to preceding apertural face, but not reaching septal foramen; anterior end of septal chamber wall attaching to adjacent previous whorl, though secondary tongue not formed (Pl. 12, fig. 13; Fig. 34). Etched wall section revealing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 15a-c, IGPS 97198A, sample BS–2, Tomiya Formation, Boso Peninsula; paratype, IGPS 97198–11, the same sample.

Remarks: – This new species is characterized by its subglobular test, perpendicularly extended aperture surrounded with many apertural grooves (D3 Type).

This species is somewhat similar to *G. gemma* (Todd), although the apertural grooves of *G. matobai* are not so much developed, the primary tongue is poorly developed (Fig. 34), and the type of perforation is entirely different from that of *G. gemma*. This species is also allied to *G. oriangulata*, *G. bisecta*, and *G. rugosa* in its test shape, but differentiated from them in having a non-tripartite aperture (E Type) and relatively smaller perforation.

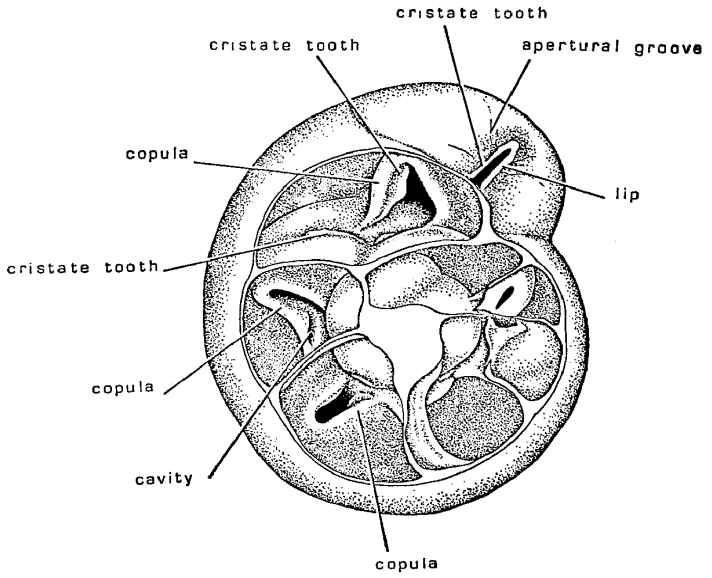


Fig. 34. Inner structure of *Globocassidulina matobai* Nomura, sp. nov.

This new species is named in hour of Dr. Yasumochi Matoba of the Institute of Mining Geology, Mining College, Akita University.

Ontogeny and measurements: – Variation in test morphology slight. Apertural grooves, however, less developed or absent in juvenile forms.

IGPS	Sample	Length	Width	Thickness
97198–1	BS–2	0.17 mm	0.16 mm	0.15 mm
97198–2	–	0.19	0.18	0.16
97198–3	–	0.23	0.20	0.18
97198–4	–	0.25	0.20	0.19
97198–5	–	0.24	0.22	0.18
97198–6	–	0.25	0.22	0.18
97198–7	–	0.24	0.24	0.21
97198–8	–	0.28	0.26	0.20
97198–9	–	0.23	0.31	0.24
97198–10	–	0.35	0.29	0.23
97198–11 (Paratype)	–	0.35	0.33	0.24
97198A (Holotype)	–	0.37	0.35	0.24

Occurrence in studied area: – Common in lower Pleistocene deposits of the Boso Peninsula and found in samples BS–1, 2, 7(B).

Globocassidulina neobrocha Nomura, sp. nov.

Pl. 1, figs. 16a–c; Pl. 19, figs. 3–6

Description: – Test medium, biconvex, nearly circular in side view, lenticular in edge view; periphery subacute, very slightly lobulate; chambers distinct, subrectangular in general shape, not inflated, alternating chambers presenting only short and triangular tips on opposite side, five pairs in last coil; sutures distinct, narrowly limbate, not depressed, almost straight; umbilical region closed; aperture a crescent narrow foramen almost parallel to peripheral margin of apertural face, with fan-shaped fragile cristate tooth projecting from posterior side; wall smooth, polished, finely perforate, translucent.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth, with calcitic microgranules on test surface; borings randomly distributed on test surface in some specimens, but their preferred location not recognizable; some borings being associated with faintly radiating striations (Pl. 19, fig. 6). Pores on all chambers rounded, becoming somewhat smaller on final chamber; no perforation observed on narrow regions of umbilicus and apertural face; average pore diameter 2.0 μm; pore density 10 pores per $20 \times 20\ \mu m^2$. Aperture E5 Type, closely resembling that of *Islandiella helenae*; aperture externally composed of cristate tooth on posterior side, secondary tongue on lower side, and lip (Pl. 19, fig. 4); cristate tooth and secondary tongue edged with b type, though lip c type (see Fig. 15); inner structure showing copula attached to preceding septal chamber wall near anterior corner of septal foramen (Fig. 35); primary tongue extending internally fringe-shaped in fully matured stages, but less developed in neanic to early ephebic stages (Pl. 19, fig. 5); cavity always recognizable; anterior septal chamber wall attaching to anterior periphery of preceding septal chamber wall, and then secondary tongue separating from that place. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 16a-c, IGPS 97206, sample BS–17, Yabu Formation, Boso Peninsula; paratype, IGPS 97206A, sample OG–21, Shibikawa Formation, Oga Peninsula.

Remarks: – This new species is characterized by its lenticular test, almost straight

and non-depressed sutures, and crescent aperture with a protruding cristate tooth.

This species somewhat resembles *G. brocha*, but is distinct in having wider chambers, straight sutures and distinct cristate tooth. This species is similar to *Cassidulina simpsonsbayensis* McCulloch (1977) in its test shape and chamber arrangement, but *G. neobrocha* differs from *C. simpsonsbayensis* in the absence of narrow keel. *Cassidulina wenmanensis* McCulloch (1977) also resembles this new species in its test shape, but differs from the latter in the position and shape of the aperture.

Ontogeny and measurements: – Crescent-shaped aperture opening obliquely to apertural face in neanic stage.

IGPS	Sample	Length	Width	Thickness
97206 (Holotype)	BS–17	0.50 mm	0.43 mm	0.22 mm
97206A (Paratype)	OG–21	0.48	0.42	0.22

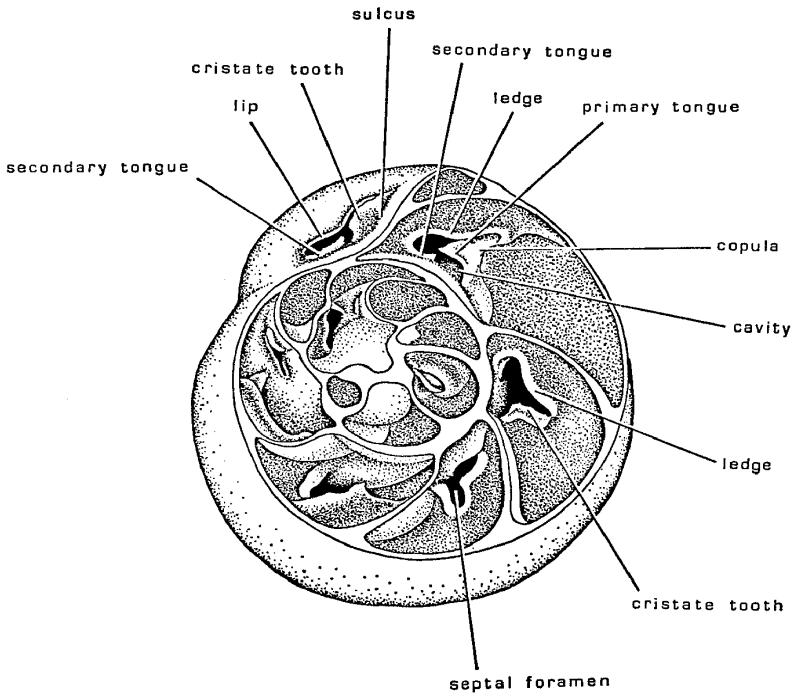


Fig. 35. Inner structure of *Globocassidulina neobrocha* Nomura, sp. nov.

Occurrence in studied area: – Rarely found in upper Pleistocene deposits of Japan occurring particularly in samples OG–21; BS–17; MM–3.

Globocassidulina subbisecta Nomura, sp. nov.

Pl. 1, figs. 17a–c; Pl. 16, figs. 7–10

Description: – Test medium, subglobular; periphery broadly rounded, slightly lobulate; chambers distinct except for early portion, broadly oval, moderately inflated, about three or four pairs making up last coil, biserially arranged throughout, increasing rapidly in size, last-formed pair making up a half of entire test; sutures slightly depressed, not limbate, moderately curved; aperture L-shaped; basal branch slightly longer than areal one in adult; wall initially thin and translucent, later thickened and semi-opaque, finely and uniformly perforated, and polished.

Polarizing microscopy: – Fragments viewed in polarized light showing jagged-granular texture.

SEM observation: – Test microtopography

smooth; calcitic microgranules covering test surface; poorly developed striae out of the aperture observed in previous test surface. Pores rounded and evenly distributed, very slightly depressed on earlier chambers, but becoming smaller on final chamber; apertural face imperforate; pore diameter 1.3 to 3.0 μm; pore density six pores per $20 \times 20\ \mu m^2$. Aperture E2 Type (Pl. 16, fig. 7), encircled by thickened lip, secondary tongue, and poorly developed cristate tooth; tips of these structure tube-shaped (see Fig. 15); inner structure showing copula glued to preceding septal chamber wall, fringe-like primary tongue, and cavity (Fig. 37); copula not reached to septal foramen; secondary tongue formed in adjacent previous coil; gap usually formed; primary tongue underdeveloped in younger stages. Etched wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 1, figs. 17a-c, IGPS 97212A, sample OK–3, upper Yonabaru Formation, Okinawa Island.

Remarks: – This new species is characterized by a relatively few chambers in the final whorl, rounded perforation, and E2 Type aperture.

In these features, *G. subbisecta* is distinct from the other described species of *Globocassidulina*, or from those species previously placed under *Cassidulina*.

The specific name refers to the apertural character.

Ontogeny and measurements: – The shape of aperture ontogenetically changed from loop shaped to L shaped (Fig. 36).

IGPS	Sample	Length	Width	Thickness	Fig. 36
97212–1	OK–3	0.09 mm	0.13 mm	0.12 mm	(1)
97212–2	–	0.15	0.13	0.12	(2)
97212–3	–	0.16	0.14	0.13	(3)
97212–4	–	0.23	0.18	0.17	(4)
97212B	–	0.23	0.20	0.17	(5)
97212–5	–	0.25	0.23	0.19	(6)
97212–6 (Paratype)	–	0.30	0.28	0.23	(7)
97212A (Holotype)	–	0.37	0.32	0.30	(8)

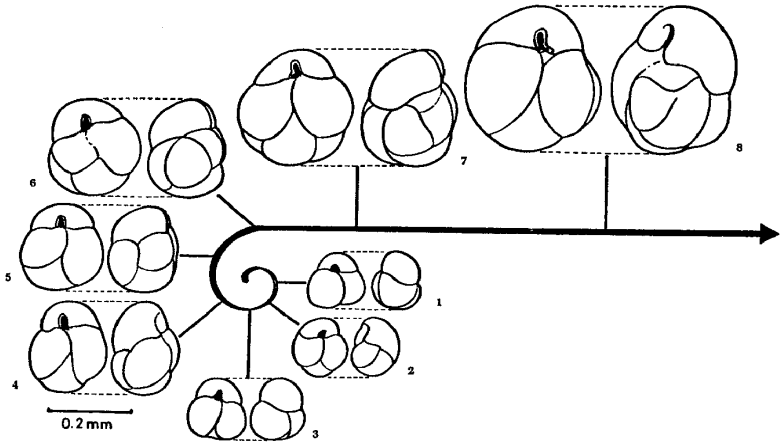


Fig. 36. Ontogeny of *Globocassidulina subbisecta* Nomura, sp. nov.

Occurrence in studied area: – Found in samples OK–3, 9, 14, 22. This species, which commonly occurs in the Yonabaru Formation and is rarely found in the Shinzato Formation, is restricted to Pliocene deposits of Okinawa Island.

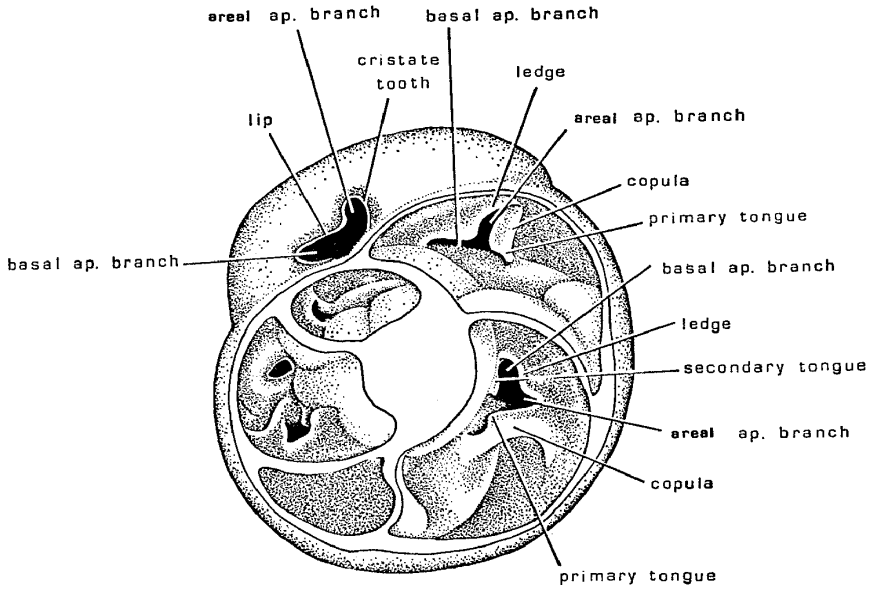


Fig. 37. Inner structure of *Globocassidulina subbisecta* Nomura, sp. nov.

Globocassidulina tsuchidai Nomura, sp. nov.

Pl. 2, figs. 4a–c; Pl. 17, figs. 3–7

Description: – Test small, broadly oval in side view, rounded-rectangular and both sides almost parallel in edge view, apertural face almost flat; periphery rounded, not lobulate; chambers obscure in earlier portion, but in later very slightly inflated, about five pairs making up adult whorl, increasing rapidly in growth, last two pairs making up about a half of entire test; sutures distinct except for earlier portion, very slight depressed, radially very slightly curved toward periphery, but almost straight; aperture large, L-shaped, with plate-like triangular apertural flap covering most of it, situated at the base of flat face; wall thin and translucent, finely and uniformly perforated, but earlier portion of test roughly uneven, gradually decrease its roughness toward later portion.
Polarizing microscopy: – Jagged-granular texture.
SEM observation: – Test microtopography rugged, somewhat vermiculated appearance on earlier portion (Pl. 17, fig. 7) and smooth on later chambers. Pores irregular in shape, depressed on earlier portion, but becoming rounded and flush with surface in later portion (Pl. 17, fig. 6); flat apertural face usually imperforate; size of irregular pores from 0.6 to 1.8 μm; rounded type 0.6 μm in average; pore density eight pores per 20×20 μm^2. Aperture E8 Type (Pl. 17, fig. 4); cristate tooth and lip edged with b and c types, lip along basal apertural branch e type (see Fig. 15); sulcus narrow and deep; apertural ridge extending from preceding chamber to previous one; inner structure showing copula attached to preceding lip of areal apertural branch (Pl. 17, fig. 5); primary tongue not seperated from copula; basal apertural branch and apertural flap becoming less developed toward younger chambers, so that in neanic stage, aperture appearing loop-shaped extending at right angles to the base (Figs. 39, 41); apertural grooves missing in younger forms. Etched wall cross section showing III Type structure.
Type and occurrence: – Holotype, Pl. 2, figs. 4a-c, IGPS 97215A, sample MU–5, Ofuna Formation, Miura Peninsula; paratype, IGPS 97215B, the same sample.
Remarks: – This species is characterized by its small oval test with compressed

apertural face, L-shaped aperture having a large triangular apertural flap, and vermiculated surface structure in the early part of the whorl.

The developmental mode of copula adhering to the preceding apertural flap is similar to that of the genus *Burseolina*.

This new species somewhat resembles *Cassidulina algida* Cushman from Recent sediments of Casco Bay, Maine, but the apertural character is quite different. *G. tsuchidai* is somewhat similar to the specimen figured by Bandy (1952) as *Cassidulina cuneata* Finely, but the former differs from the latter in its test shape, tripartite aperture, and well-developed apertural flap. *Cassidulina* sp. D of Todd (1957b) from the Miocene of Saipan, Mariana Islands, is also closely allied to *G. tsuchidai* in its test shape and apertural feature, but *G. tsuchidai* differs from Todd's specimen in having not so strongly curved and incised sutures.

The species is named in honor of the late Dr. Sadajiro Tsuchida of Waseda University.

Ontogeny and measurements: – Ontogeny of this species shown in Fig. 38. In neanic to early ephebic stages test subglobular in outline.

IGPS	Sample	Length	Width	Thickness	Fig. 38
97215–1	MU–5	0.16 mm	0.12 mm	0.13 mm	(1)
97215–2	–	0.20	0.14	0.13	(2)
97215–3	–	0.20	0.15	0.16	(3)
97215–4	–	0.20	0.15	0.14	(4)
97215–5	–	0.22	0.16	0.14	(5)
97215–6	–	0.22	0.17	0.17	(6)
97215–7	–	0.24	0.18	0.15	(7)
97215–8	–	0.23	0.17	0.16	(8)
97215–9	–	0.29	0.22	0.19	(9)
97215A (Holotype)	–	0.32	0.23	0.21	

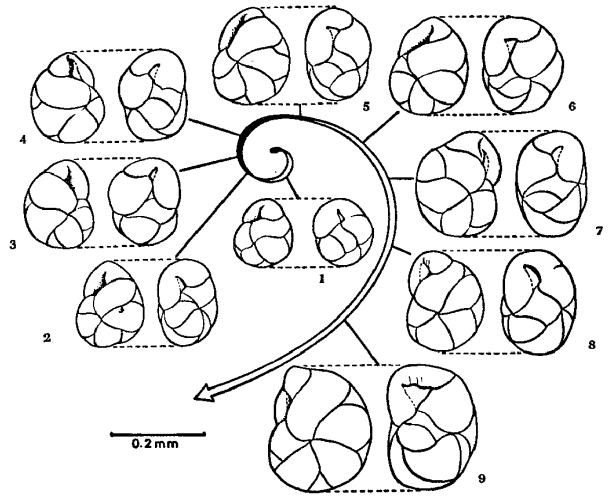


Fig. 38. Ontogeny of *Globocassidulina tsuchidai* Nomura, sp. nov.

Occurrence in studied area: – Found in samples ST–7; KM–51; CH–3, 10; BS–3-6, 7(A), (B), 8, 9, 12-17; MU–1-6, 11; MM–2, 3, 5; NO–2; OK–4, 7, 10(A), 11, 19, 20–23. This species is common in Pleistocene sediments of the Pacific side of Japan.

Globocassidulina rugosa Nomura, sp. nov.

Pl. 2, figs. 1a–c; Pl. 16, figs. 5, 6

Description: – Test medium, stout, nearly circular in side view, oval in edge view; periphery rounded, not lobulate; chambers distinct, suboval, very slightly inflated, four to five pairs in last coil, with a set of short tapering and overlapped ends at periphery; sutures distinct, very narrowly limbate, not depressed; aperture tripartite, consisting of basal branch and slightly longer areal one, both branches orthogonally organized; wall rather thick, rough, coarsely perforated, diffusely reflected, translucent.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography somewhat rugged, with depressed pores;

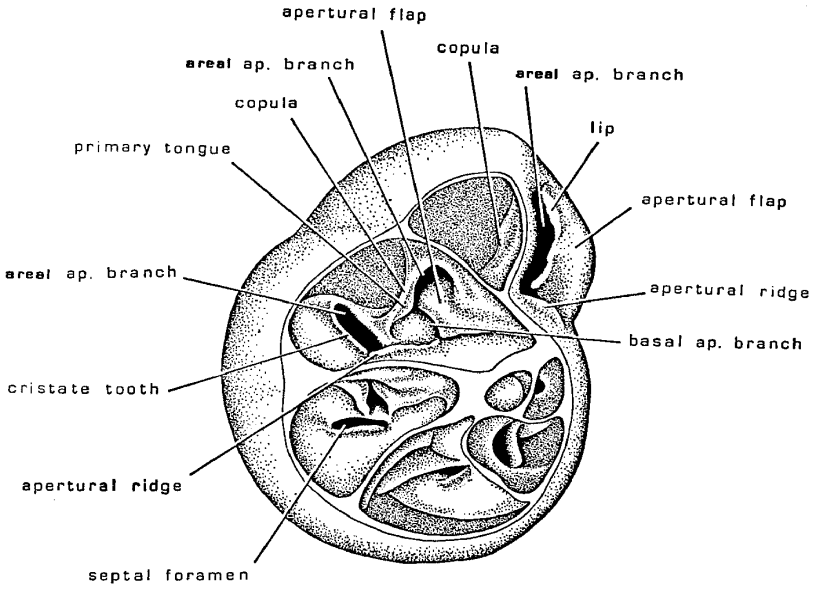


Fig. 39. Inner structure of *Globocassidulina tsuchidai* Nomura, sp. nov.

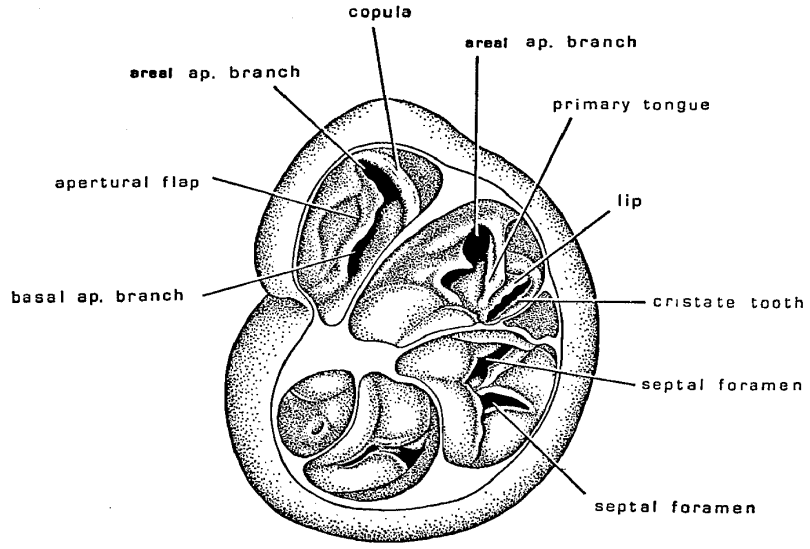


Fig. 40. Inner structure of *Globocassidulina tsuchidai* Nomura, sp. nov.

interpore regions inflated, giving diffuse reflection. Pores rounded, small (approximately 0.45 μm) on earlier wall, but larger (approximately 0.66–1.00 μm) on final chamber; apertural face imperforate; average pore diameter 0.6 μm; pore density 16 pores per 20×20 μm^2. Aperture E7 Type; inner structure showing posterior septal chamber wall infolded to form cristate tooth externally and primary tongue with cavity (Pl. 16, fig. 6; Fig. 42); copula attaching to anterior corner of preceding basal apertural branch; sulcus rather shallow; tips of both cristate tooth and lip c type structure (see Fig. 15); anterior septal chamber wall attaching to adjacent previous coil, and forming poorly developed secondary tongue internally; apertural ridge thinly formed. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 1a-c, IGPS 97219A, sample BS–7 (A), Otadai Formation, Boso Peninsula;

paratype, IGPS 97219B, the same sample.

Remarks: – The diagnostic features of this species are its oval test with non-lobulate periphery and somewhat diffuse surface in reflected light. It closely resembles *G. oriangulata* in its tripartite aperture and developmental mode of toothplate, but differs from the latter in having a large typical ellipsoidal test, non-lobulate periphery, and more thickly calcified wall. *G. bisecta* is also close to this species in its external apertural feature, but features are different in internal structure and chamber shape.

In the test shape, this species apparently resembles *Cassidulina symmetrica* LeRoy (1944), but differs from the latter in the number of chambers and apertural characters.

The specific name refers to the test surface.

Ontogeny and measurements: – Test shape showing little ontogenetic variation, but often difficult to discriminate the present species from juvenile forms of *G. oriangulata*.

IGPS	Sample	Length	Width	Thickness	Fig. 41
97219–1	BS–7(A)	0.22 mm	0.18 mm	0.16 mm	(1)
97219–2	–	0.26	0.21	0.18	(2)
97219–3	–	0.27	0.22	0.19	(3)
97219–4	–	0.35	0.28	0.23	(4)
97219–5	–	0.36	0.29	0.23	(5)
97219–6	–	0.39	0.34	0.23	(6)
97219A (Holotype)	–	0.43	0.38	0.25	

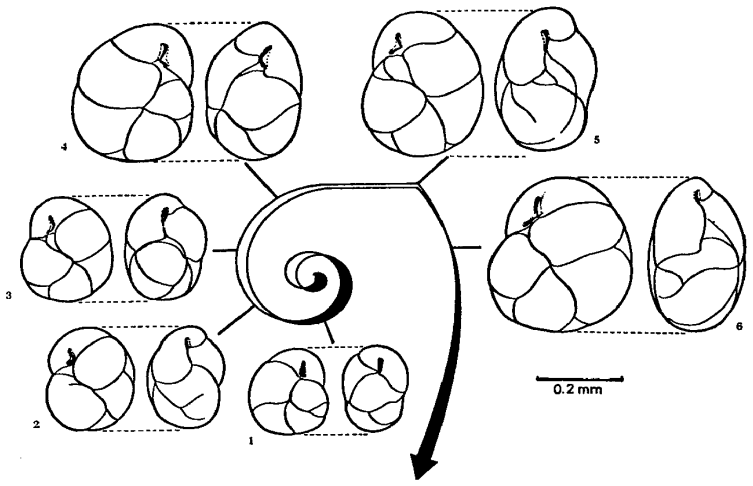


Fig. 41. Ontogeny of *Globocassidulina rugosa* Nomura, sp. nov.

Occurrence in studied area: – Found in samples BS–4-6, 7 (A), (B); MU–1, 6; OK–11, 23. Common in the Kiwada and Otadai Formations, but rare in the Shinzato Formation.

Globocassidulina bisecta Nomura, sp. nov.

P. 2, figs. 2a–c, 3a–c; Pl. 2, figs. 3a–c; Pl. 14, figs. 8–12; Pl. 15. figs. 1–5

Cassidulina subglobosa Brady. Asano and Nakamura, 1937a, p. 147, pl. 8, figs. 3a, b; Asano, 1951, pt. 7, p. 4, figs. 17, 18; Higuchi, 1954, pl. 3, figs. 25a, b; Kuwano, 1962, pl. 16, fig. 3; Kikuchi, 1964 (part), pl. 7, figs. 2–5 (not fig. 1); Aoki, 1964, pl. 25, fig. 13; Matoba, 1967, p. 253, pl. 28, figs. 15a–c, 16a, b, 17, 18.

Globocassidulina subglobosa (Brady). Chiji and Lopez, 1968, p. 107, pl. 15, figs. 5a, b; Kameyama, 1972, pl. 31, figs. 6a, b; Hasegawa, 1979 (part), p. 149, pl. 8, figs. 9a, b (not figs. 10a, b).

Description: – Test medium to large, sub-

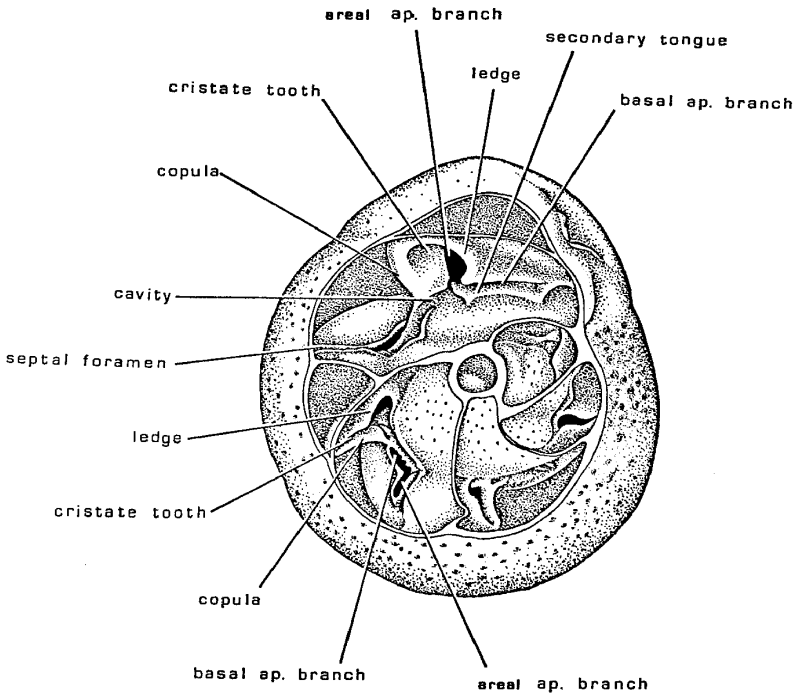


Fig. 42. Inner structure of *Globocassidulina rugosa* Nomura, sp. nov.

globular, somewhat compressed, almost circular in side view; periphery broadly rounded, distinctly lobulate; chambers distinct, oval, inflated, usually four pairs making up last coil, gradually increasing in size as added; sutures distinct, narrowly limbate, radiate, moderately curved, slightly depressed; umbilical region on each side depresed and closed; aperture tripartite, consisting of basal slit and almost orthogonally organized areal slit; wall initially thin and transparent to semi-translucent, later thick, polished, finely and uniformly perforated.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth, with calcitic microgranules. Pores on all chambers rounded (Pl. 15, figs. 4, 5), not depressed, and evenly distributed, but becoming smaller on final chamber; apertural face imperforate; average pore diameter 1.0 μm; pore desnity 10 pores per 20×20 μm^2; pores on inner surface approximately 1.2 μm in diameter, slightly depressed, with concentric grooves around them (Pl. 29, fig. 3). Aperture E7 Type, with low apertural ridge; proximal end of copula attaching to preceding apertural face apart from septal foramen, and forming small primary tongue in basal part of copula (Pl. 14, fig. 8; Figs. 44, 45); anterior septal chamber wall attaching to previous coil, though secondary tongue not formed (Pl. 14, figs. 8–12; Fig. 45); tripartite aperture appearing to be only loop-shaped in previous whorl (Pl. 14, fig. 12; Fig. 46); proloculus aperture externally rounded without lip and cristate tooth (Pl. 14, fig. 10), but in internal view apertural inner rim somewhat swelled (Pl. 15, fig. 1). Wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 2a-c, IGPS 97220A, sample BS–9, Kokumoto Formation, Boso Peninsula; paratype, IGPS 97220B, the same sample; paratype, Pl. 2, figs. 3a-c, IGPS 97221, sample SW–3, Shichiba Formation, Sado Island, Niigata Prefecture.

Remarks: – As shown in the synonymy, most of the specimens which have been referred to *G. subglobosa* by Japanese

authors can be assigned to *G. bisecta*. Although this species is closely related to the original figures of *G. subglobosa* (= *Cassidulina subglobosoa* Brady, 1884) in its external test shape and the mode of chamber inflation, but differs in the apertural characters and its position. As will be mentioned in the remarks of *G. subglobosa*, *G. subglobosa* does not have the tripartite feature as shown by matured specimen of *G. bisecta*.

This species is also closely allied to *G. oriangulata* and *G. rugosa* in the tripartite apertural character, but is distinguished in having more inflated chambers, convex umbilicus, and copula which does not adhere to the anterior corner of the preceding aperture.

Compressed forms of *G. bisecta* are somewhat similar to *G. depressa* in the shape of test, and it seems to intergrade with the latter. Nevertheless, *G. bisecta* can be distinguished in having more inflated chambers and centrally located position of copula on the penultimate apertural face.

The present species is widespread in the Pacific borderland and modern Pacific Ocean, and is especially very abundant in the *G. subglobosa* Zone of the Boso Peninsula (Aoki, 1963) and Choshi area (Matoba, 1967), and is sporadically found in the Japan Sea borderland.

This species is named after the Latin *bis* meaning twice or in two ways, and *sectus* meaning divide, cleave, or part, with reference to its apertural shape.

Ontogeny and measurements: – In neanic to early ephebic stages, basal apertural branch not formed (Fig. 43).

IGPS	Sample	Length	Width	Thickness	Fig. 43
97220–1	BS–9	0.12 mm	0.12 mm	0.11 mm	(1)
97220–2	–	0.13	0.11	0.10	(2)
97220–3	–	0.15	0.12	0.12	(3)
97220–4	–	0.15	0.13	0.11	(4)
97220–5	–	0.17	0.14	0.12	(5)
97220–6	–	0.19	0.16	0.13	(6)
97220–7	–	0.20	0.18	0.13	(7)
97220–8	–	0.19	0.17	0.17	(8)
97220–9	–	0.21	0.19	0.15	(9)
97220–10	–	0.23	0.21	0.16	(10)
97220–11	–	0.28	0.26	0.20	(11)

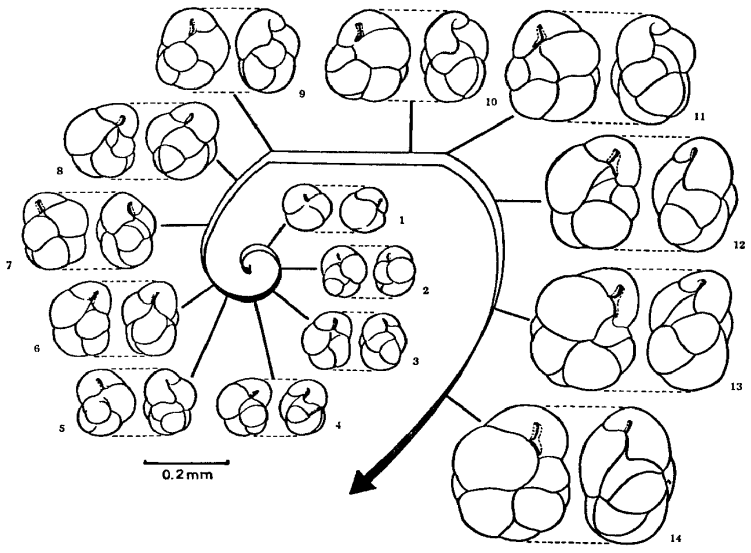


Fig. 43. Ontogeny of *Globocassidulina bisecta* Nomura, sp. nov.

97220–12	–	0.29	0.26	0.20	(12)
97220–13	–	0.32	0.30	0.20	(13)
97220–14	–	0.35	0.31	0.22	(14)
97220A (Holotype)	–	0.35	0.31	0.23	
97221 (Paratype)	SW–3	0.53	0.43	0.35	

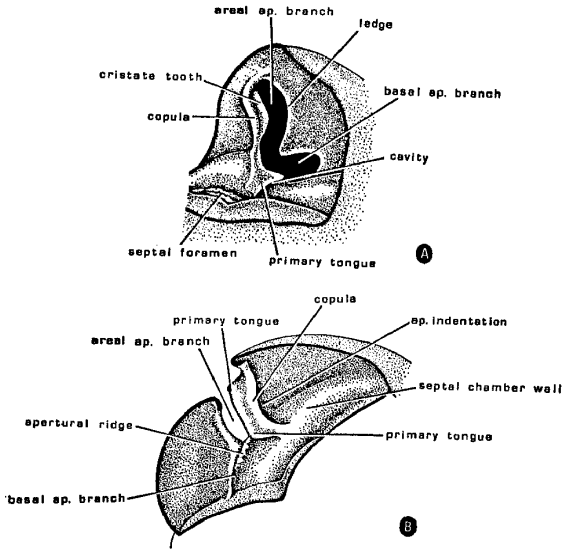


Fig. 44. Apertural modification of the final and penultimate chambers of *Glbocassidulina bisecta* Nomura, sp. nov.

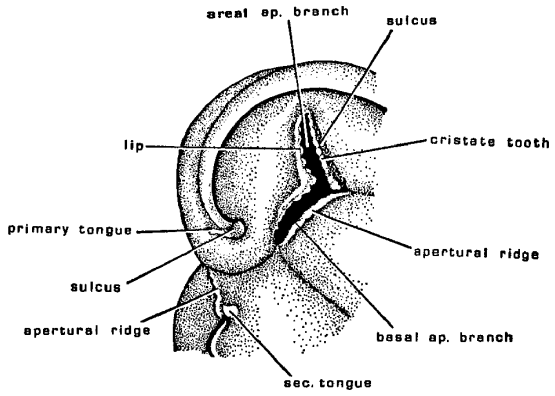


Fig. 45. Apertural modification of the final and penultimate chambers of *Globocassidulina bisecta* Nomura, sp. nov.

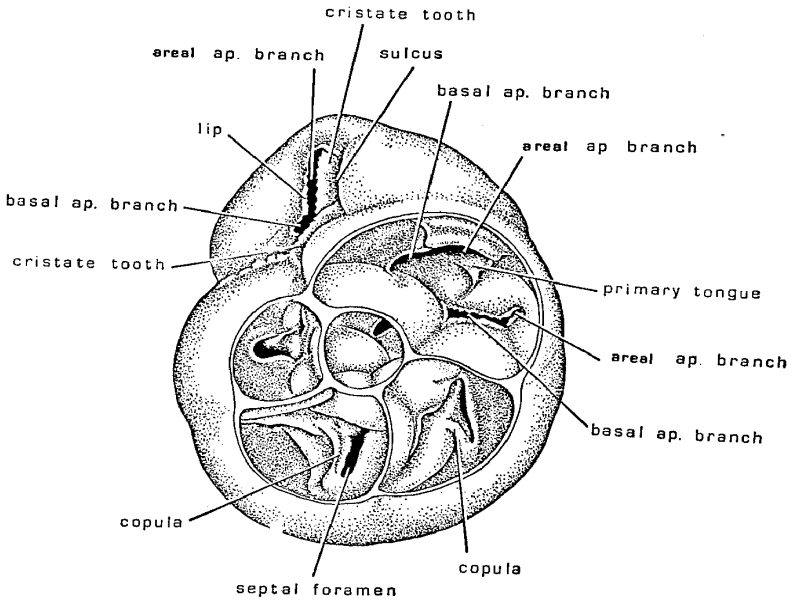


Fig. 46. Inner structure of *Globocassidulina bisecta* Nomura, sp. nov.

Occurrence in studied area: – Found in samples NT–2; AR–2, 3, 6, 8; SW–1-7; ASH–10; CH–7-12; BS–9, 10.

Genus *Evolvocassidulina* Eade, 1967

Evolvocassidulina Eade, 1967, p. 431.

Type species: – *Cassidulina orientalis* Cushman, 1922b, p. 129: Recent, off Poor Knights Islands, east of New Zealand.

Diagnosis: – Test free, subglobular to elongate in outline; periphery broadly rounded to acute, with or without keel; chambers biserially arranged, in early stage much enrolled, later chambers more elongate than earlier chambers; aperture subterminal, oval to elongate loop-shaped, bordered by narrow lip, with protruded or non-protruded cristate tooth; wall calcareous, optically granular in texture, perforate, surface smooth (partly from Eade, 1967, p. 431).

Stratigraphic distribution: – Upper Eocene to Recent.

Remarks: – This genus was erected by Eade (1967) based on the Recent Pacific species *Cassidulina orientalis* Cushman, which was separated by Cushman (1922b) from the North Atlantic species *Cassidulina bradyi* Norman illustrated originally by Brady (1884).

Evolvocassidulina somewhat resembles *Cassidulinoides* Cushman in the manner of growth except for wall structure. In addition, Eade (1967, p. 431) pointed out other differences between the two as follows: "*Cassidulinoides* has squat, globose or subglobose chambers, ... and a tightly curved internal tooth, often not visible externally, attached at its base to the penultimate chamber at the distal edge of the septal foramen. *Evolvocassidulina* has elongate, compressed to subglobular chambers .... attached at its base to the wall of the penultimate chamber at or very near the basal margin." Generally, Japanese evolvocassidulinid specimens have apertures either with typical toothplate or a much reduced one without having a primary tongue of internal free part of toothplate. The above accounts appear to lead us to the conclusion that the toothplate is not essential structure in supraspecific taxonomy.

The following three species, *Cassidulinoides tenuis* Phleger and Parker, *Cassidulinoides inflata* LeRoy, and *Cassidulinoides seranensus* Germeraad were included in *Evolvocassidulina* by Eade (*op. cit.*) at the time of his proposal of this genus. But a detailed investation of inner structure, mode of coiling, and apertural characters shows that the first species should be placed in *Hastilina*, gen. nov. On the basis of their almost uncoiled test, the last two species can be transferred to *Lernella* in possessing an apertural plate instead of toothplate.

This genus is closely allied to *Globocassidulina* having the aperture of C or D Type during the youngest growth stage, but a remarkable difference is acquired in the mature growth stage which shows uncoiling biserial chamber arrangement. Thus it is admittable that *Evolvocassidulina* is phylogenetically closely related to *Globocassidulina* and evolved from the latter.

The oldest geologic occurrence may be in late Eocene. In Japan, this genus has been recorded from Miocene to Recent strata as *Cassidulinoides*.

Evolvocassidulina eadei Nomura, sp. nov.

Pl. 2, figs. 5a, b; Pl. 19, figs. 12, 13; Pl. 20, figs. 1–3

Description: – Test medium, elongate, reniform in outline, compressed laterally, early portion tightly coiled, later portion uncoiled and biserially arranged; periphery narrawly rounded, not lobulate; chambers distinct, low and broad, not inflated, about six to seven pairs in adult, gradually increasing in size as added, biserial chambers overlapping at periphery, and showing only small triangular portion of each set on one side; sutures distinct, limbate, flush with surface, very slightly curved toward periphery, but almost straight, somewhat obliquely set to axis of growth in uncoiled portion; aperture subterminal, oval in shape;

wall initially thin and translucent, later thick, semi-opaque, polished, very finely perforate.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth; the uppermost test surface consisting of calcitic microgranules. Pores fine, pore margin flush with surface, evenly distributed, and rounded (Pl. 20, fig. 3); average pore diameter 0.6 μm; pore density 17 pores per 20×20 μm^2. Inner structure showing aperture bordered by thickened lip of b type (see Fig. 15) (Pl. 19, fig. 13; Pl. 20, fig. 1); apertural construction very similar to that of *Cassidulinoides subcylindricus* sp. nov. Etched wall structure III Type.

Type and occurrence: – Holotype, Pl. 2, figs. 5a, b, IGPS 97227, sample OK–15, Yonabaru Formation, Okinawa Island; paratype, IGPS 97227 A, B, the same sample.

Remarks: – This species is characterized by an oval aperture (C3 Type), the absence of primary tongue, and limbate sutures flushed with the surface.

Evolvocassidulina eadei is very closely allied to an East Pacific form referred to as *Cassidulina bradyi* Norman by Brady (1884), in the shape of test, mode of sutural arrangement, and chamber form in side view. Regarding its aperture, Brady stated that "aperture loop-shaped, situated on the inner face of the terminal chamber." Among Brady's original figures of *Cassidulina bradyi*, the specimen from the Pacific was referred to *Cassidulina orientalis* by Cushman (19–22b). Later, Eade (1967) carefully reviewed the topotypes of *E. orientalis* and stated as follows: "The compressed appearance of *E. orientalis* is accentuated by the presence of a narrow peripheral keel in the coil stage. The periphery of the uncoiled stage, though lacking a keel, is more acute than in *C. bradyi*. .... The aperture is loop-shaped .... It (=toothplate) extends across most of the aperture and upwards usually to just above the lip of the aperture. The actual opening therefore consists of a narrow slit." The protruded cristate tooth is clearly displayed in his illustration.

These features are quite different from *E. eadei*. This new species is not so strongly compressed, and the periphery is narrowly rounded but never keeled in all portion. The aperture is loop-shaped but oval and lacks toothplate throughout ontogeny. Therefore, the present writer treats this form as a distinct species.

This species differs from *E. bradyi* (s. s.) in having a more thickened, stout test, more closely coiled early portion, limbate sutures, and non-loop shaped aperture, and in lacking toothplate. *E. belfordi* Nomura, sp. nov. is closely allied to this species in the chamber form and nature of limbate sutures. Particularly in young forms, it is difficult to discriminate these two species by external morphology alone. However, *E. eadei* differs from *E. belfordi* in the shape of aperture which does not have a protruded cristate tooth and primary tongue and in having a more elongate test form in matured specimens.

The specific name is dedicated to Dr. J.V. Eade of Department of Scientific and Industrial Research, New Zealand Oceanographic Institute, who investigated Recent cassiduline foraminifera off New Zealand.

Ontogeny and measurements: – The neanic stage having a more rounded test. The shape of aperture not differing throughout ontogeny (Fig. 47).

IGPS	Sample	Length	Width	Thickness	Fig. 47
97227–1	OK–15	0.16 mm	0.13 mm	0.11 mm	(1)
97227–2	–	0.19	0.15	0.13	(2)
97227–3	–	0.20	0.14	0.13	(3)
97227–4	–	0.20	0.15	0.14	(4)
97227–5	–	0.25	0.17	0.14	(5)

97227–6	–	0.30	0.20	0.15	(6)
97227–7	–	0.33	0.21	0.16	(7)
97227–8	–	0.33	0.21	0.15	(8)
97227–9	–	0.35	0.21	0.16	(9)
97227–10	–	0.37	0.21	0.21	(10)
97227 (Holotype)	–	0.48	0.27	0.18	
97227A (Paratype)	–	0.58	0.36	0.25	
97227B (Paratype)	–	0.42	0.23	0.16	

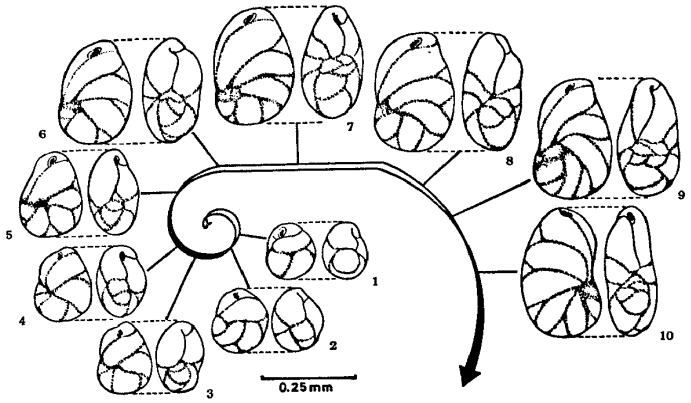


Fig. 47. Ontogeny of *Evolvocassidulina eadei* Nomura, sp. nov.

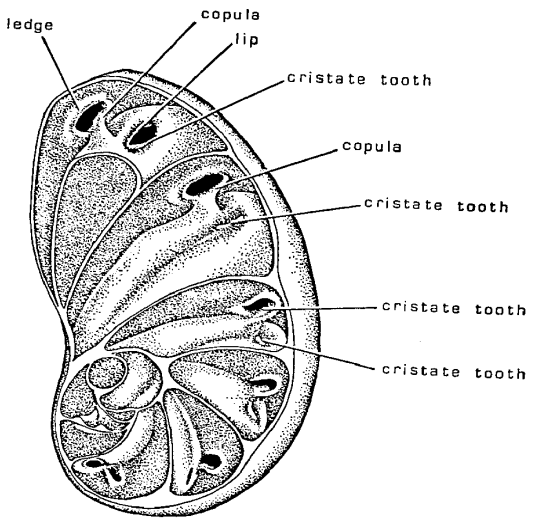


Fig. 48. Inner structure of *Evolvocassidulina eadei* Nomura, sp. nov.

Occurrence in studied area: – Found in samples OK–2, 5, 6, 13, 14, 15, 21. Known only from Okinawa Island.

Evolvocassidulina belfordi Nomura, sp. nov.

Pl. 2, figs. 6a–c; Pl. 20, figs. 8–10, 12

Cassidulinoides bradyi (Norman). Cushman, 1930, p. 58, pl. 11, figs. 8a, b; Cushman and Cahill, 1933, p. 32, pl. 12, figs. 4a, b.

Cassidulinoides braziliensis (Cushman). LeRoy, 1964, p. F41, pl. 12, figs. 3, 4.

Globocassidulina oblonga (Reuss). Belford, 1966, p. 150, 151, pl. 26, figs. 1–4, text-fig. 17, nos. 7, 8.

Description: – Test medium, longer than broad, compressed, pyriform in shape, with last two chambers tending to uncoiled and apertural end bluntly rounded; periphery narrowly rounded, not lobulate; chambers distinct, not inflated, about five pairs making up entire test, biserially arranged throughout; sutures distinct, limbate, flush with surface, slightly curved near periphery, but almost straight; aperture an elongte slit, subterminal, extending upward almost to the top of poorly developed apertural face; wall initially thin and translucent, later thick and semi-opaque, smooth and polished, very finely perforate.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth; calcitic microgranules on test surface; some specimens have small lumps on surface, but they probably due to crystal overgrowth (Pl. 20, fig. 10). Pores on earlier chambers slit-shaped, and arranged in parallel toward aperture (Pl. 20, fig. 10); on later chambers, pores fine, rounded, and pore margin flush with surface; average size of slit-shaped pore 1.3 μm; average pore diameter of rounded type 0.3 μm; pore density 14 pores per $20 \times 20\ \mu m^2$. Inner structure

showing toothplate with sulcus turned sharply inward (Pl. 20, figs. 8, 9), and composed of primary end of copula attaching to anterior septal chamber wall near septal foramen (Fig. 50). Etched wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 6a-c, IGPS 97228, sample OK–10 (A), Yonabaru Formation, Okinawa Island; paratype, IGPS 97228A, the same sample.

Remarks: –This new species is considered to be conspecific with those figured as *Cassidulinoides bradyi* (Norman) by Cushman (1930), and Cushman and Cahill (1933), and the form named as *Globocassidulina oblonga* by Belford (1966). *E. belfordi* is principally characterized by a pyriform test with poorly developed apertural face.

As may be seen from the figures, this species is very similar to *Cassidulinoides compacta* Cushman and Ellisor in the gross test morphology. However, it can be distinguished by the trapezoidal outline of last-formed pair and its thick test. Papua New Guinea specimens referred to *G. oblonga* (Reuss) by Belford (1966) can be clearly identified with this species in all respects. The apertural character of *E. belfordi* is quite different from that of *Cassidulina oblonga* Reuss. In addition, the chamber form of this new species is different from it.

LeRoy (1964) referred this form to *Cassidulinoides braziliensis* (Cushman). However, his specimen from the Shinzato Formation is more closely identifiable with *E. belfordi*.

The specific name is dedicated to Dr. D.J. Belford of the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, Australia, who clarified the inner structure and wall structure of many species from Papua New Guinea.

Ontogeny and measurements: – In neanic stage, test rounded in side view (Fig. 49).

IGPS	Sample	Length	Width	Thickness	Fig. 49
97228–1	OK–10(A)	0.15 mm	0.12 mm	0.10 mm	(1)
97228–2	–	0.21	0.17	0.13	(2)
97228B	–	0.22	0.16	0.14	(3)
97228–3	–	0.26	0.21	0.15	(4)
97228–4	–	0.28	0.21	0.15	(5)
97228–5	–	0.30	0.23	0.15	(6)
97228–6	–	0.33	0.24	0.15	(7)
97228–7	–	0.35	0.21	0.16	(8)
97228–8	–	0.35	0.26	0.15	(9)
97228 (Holotype)	–	0.38	0.25	0.18	(10)
97228–9	–	0.40	0.26	0.18	(11)
97228A (Paratype)	–	0.41	0.25	0.17	

Occurrence in studied area: – Found in samples OK–1-5, 7, 9, 10 (A), (B), 11-13, 16-20, 22, 23. Common in Pliocene deposits of southern Okinawa Island.

Previous record of occurrence: – Miocene, Choctawhatchee Formation, Florida (Cushman, 1930); Miocene, coastal plain of eastern United States (Cushman and Cahill, 1933); Pliocene, Shinzato Formation, Okinawa Island, Japan (LeRoy, 1964); Upper Miocene, New Guinea (Belford, 1966).

Genus *Hastilina* Nomura, gen. nov.

Type species: – *Virgulina mexicana* Cushman, 1922b, p. 120, pl. 23, fig. 8: Recent, Albatross Station D2395, Gulf of Mexico.

Diagnosis: – Test free, fusiform in outline, rounded to oval in transverse section, loosely coiled in early portion, later uncoiling; periphery broadly rounded; chambers more elongate, greater in height than breadth, non-twisted biserial arrangement throughout; last pair strongly

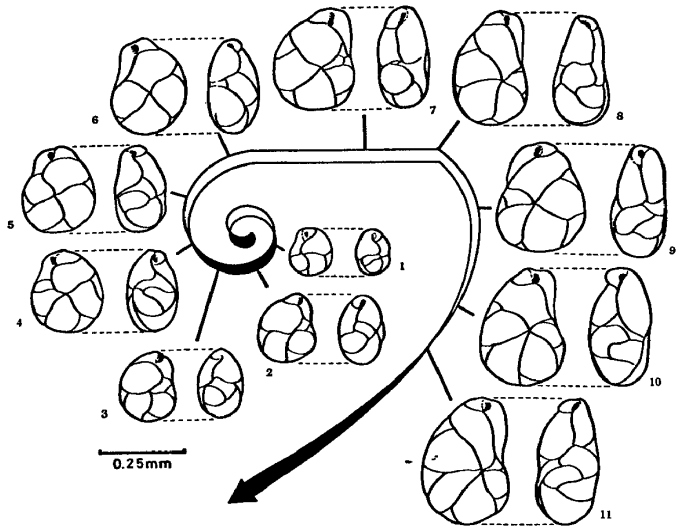


Fig. 49. Ontogeny of *Evolvocassidulina belfordi* Nomura, sp. nov.

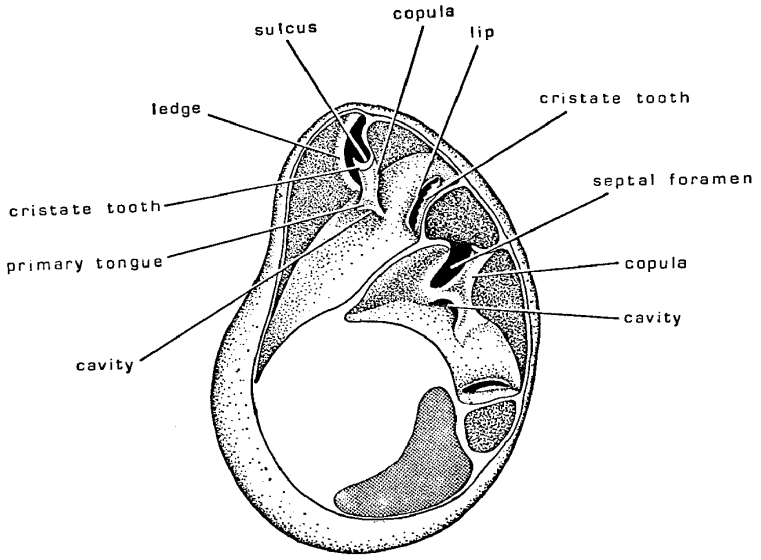


Fig. 50. Inner structure of *Evolvocassidulina belfordi* Nomura, sp. nov.

embraces early formed chambers, so that only a few chambers visible in ventral side; sutures not depressed, oblique to axis of test growth; wall calcareous, finely perforate, optically granular in texture, surface smooth and polished; aperture subterminal, elongate, loop-shaped extending up the base of poorly developed apertural face.

Stratigraphic distribution: – Oligocene to Recent.

Remarks: – Many species of this genus have hitherto been described under the name of *Virgulina*, *Fursenkoina* and *Cassidulinoides*, and also sometimes *Cassidella*.

Hastilina is very closely allied to *Fursenkoina* in the general test shape and the possession of granular wall texture, and narrow apertural face with the D Type aperture. As pointed out and described by Loeblich and Tappan (1957, 1964a), however, in early portion, *Fursenkoina* has a highly twisted biserial cham-

ber arrangement, whereas *Hastilina* gen. nov. has non-twisted one. Moreover, *Hastilina* is characterized by its more or less loosely coiled test (E Type, see Fig. 9) equipped with an aquiline initial portion in microspheric forms.

The new genus *Hastilina* is somewhat similar to *Cassidella* redefined by Loeblich and Tappan (1964a). However, when compared with the description and illustration of *Cassidella*, the most characteristic differences between the two are in the chamber forms and arrangements.

Hastilina is differentiated from *Cassidulinoides* and *Lernella* in such features as wall structure and apertural characters.

The stratigraphic distribution of *Hastilina* ranges from the Oligocene to Recent. It is rather difficult to establish the evolution of this genus. A question may be raised on the phylogenetic relationship of this genus with *Fursenkoina*. Two origins may be considered; that is, *Hastilina* may have emerged from globocassiduline forms or have branched out from *Fursenkoina* by untwisting and uncoiling its test formation. The writer is at present inclined to consider the former derivation. In any case, further work on the *Fursenkoina* is required in order to clarify their relationship in detail.

The generic name is from the Latin *hastile* meaning spear, with reference to the test shape.

Hastilina mexicana (Cushman), 1922

Pl. 2, figs. 7a–c; Pl. 3, fig. 4

Virgulina subsquamosa Egger. Brady, 1884 (part), p 415, pl 52, figs. 10a, b, 11a, b (not figs. 7, 8, 9).

Virgulina mexicana Cushman, 1922b, p. 120, pl. 23, fig. 8; Cushman, 1937, p. 29, pl. 5, fig. 4; Phleger and Parker, 1951, p. 19, pl. 9, figs. 6a, b, 7a, b, 8a, b; Phleger, Parker and Peirson, 1953, p. 34, pl. 7, figs. 6, 7; Parker, 1958, p. 272, pl. 4, figs. 26, 27; Asano, 1958a, p. 14, 15, pl. 4, figs. 1a, b, 2a, b; Ishiwada, 1964, p. 39, pl. 4, fig. 58.

Cassidulinoides subsquamosa (Egger). Hofker, 1951b, figs. 209a, b, c, 210.

Cassidulinoides bifrons Drooger, 1953, p. 140, pl. 24, figs. 14a, b, 15a, b.

Virgulina rotundata Parr. Barker, 1960, p. 106, pl. 52, figs. 10a, b, 11a, b.

Virgulina bradyi Cushman. Matsunaga, 1963, pl. 41, figs. 12a, b.

"*Virgulina*" *rotundata* Parr. Kameyama, 1972, p. 204, pl. 31, figs. 1a, b.

Description: – Test medium, elongate, fusiform, about twice as long as broad, very slightly compressed, bluntly pointed at initial end, not twisted on growth axis, somewhat curved in early portion, but almost straight in side view; periphery broadly rounded, not lobulate, broadly oval in cross section; chambers distinct, elongate oval, not inflated, about three to four pairs, biserially arranged throughout; biserial chambers overlapping obliquely to an axis of growth at peripheral margin, last-formed pair much elongate and making up about a half of entire test, but embracing almost all of test in front view; sutures distinct, very slightly curved, not depressed; aperture subterminal, an elongate loop in a depression of apertural face; wall very thin, smooth, polished, finely perforate, translucent.

Polarizing microscopy: – Fragments of test wall showing mosaic-granular texture.

SEM observation: – Test microtopography smooth; calcitic microgranules covering test surface. Pores fine, rounded, but slit-like on earlier formed chambers near aperture; average pore diameter of rounded type 0.3 μm and length of elongate type 0.6 μm; pore density 16 pores per 20×20 μm^2. Inner structure showing apertural characters identical with those of *H. subtenuis* sp. nov.; subterminal and elongate loop-shaped aperture resulting from attachment of anterior side to posterior side with indistinct cristate tooth. Etched wall section showing IV Type structure (Pl. 3, fig. 3).

Type and occurrence: – Holotype, Pl. 2, figs. 7a-c, IGPS 97233, sample OK–16, Yonabaru Formation, Okinawa Island.

Remarks: – The present specimens are characterized by a fusiform test and much embraced early portion by the last-formed pair. This species was originally described by Cushman (1922b); although his figure is not detailed enough (only dorsal side is figured), the biserial chamber arrangement can be clearly observed.

This species may include specimens from Tahiti, referred to *Virgulina subsquamosa* Egger (1857) by Brady (1884) in the shape of test, chamber forms, and biserial chamber arrangement. But Egger's original forms are rather allied to a bolivine form. The same is true for Hofker (1951b) who illustrated the external apertural features and internal structure of his *Cassidulinoides subsquamosa*. Parr (1950) considered that Brady's forms could be included in his new species, *V. rotundata*. This view was supported by Barker (1960). However, a western Australian species *V. rotundata* is more compressed on both ventral and dorsal sides. A close examination of illustrations of the holotype of *V. rotundata* suggests that Brady's form should be identified with *H. mexicana*.

Another allied form *Cassidulinoides bifrons* proposed by Drooger (1953) from the Miocene of Aruba Island coincides well with the present species in its test shape, chamber form, and apertural character.

Ontogeny and measurements: – Ontogenetic variation slight.

IGPS	Sample	Length	Width	Thickness
97233	OK–16	0.41 mm	0.28 mm	0.25 mm

Occurrence in studied area: – Found in samples CH–2, 7, OK–7, 9, 12, 15, 16.

Previous record of occurrence: – Recent, off Tahiti (Brady, 1884); Recent, Gulf of Mexico (Cushman, 1922b; Phleger and Parker, 1951); Recent, North Atlantic Ocean (Phleger, Parker and Peirson, 1953); Recent, off Sumatra (Hofker, 1951 b); Recent, eastern Mediterranean (Parker, 1958); Recent, Tosa Bay (Asano, 1958a); Recent, off Inubo-saki (Ishiwada, 1964); Miocene, Aruba Island (Drooger, 1953); Miocene, Onnagawa Formation, Japan (Matsunaga, 1963); Pleistocene, Koyu Formation (Takanabe Member), Southeast Kyushu, Japan (Kameyama, 1972).

Hastilina subtenuis Nomura, sp. nov.

Pl. 2, figs. 14a–c; Pl. 3, fig. 8; Pl. 25, fig. 12

Cassidulinoides tenuis Phleger and Parker. LeRoy, 1964, p. F41, pl. 12, figs. 1, 2.

Description: – Test medium to large, elongate fusiform with tapering end in general outline, slightly compressed on two sides, bluntly pointed at initial end, loosely coiled in early portion but almost straight in later; periphery broadly rounded, very slightly lobulate on ventral side, not lobulate on dorsal side; chambers distinct, elongate oval, not inflated, about three to four pairs in adult, biseri ally arranged, obliquely set on an axis of growth; sutures distinct, slightly curved, not depressed, not limbate; aperture subterminal, and elongate loop extending obliquely from the base to near apex of last-formed apertural face; wall very thin, smooth, polished, finely perforate, translucent.

Polarizing microscopy: – Wall mosaic-granular texture.

SEM observation: – Test microtopography smooth. Pores fine and evenly distributed; sutures and apertural face imperforate. Pores rounded and pore margin flush with surface; average pore diameter 0.4 μm; pore density 6 pores per 20×20 μm^2. Inner structure showing copula without primary tongue built up of inward-bending septal chamber wall in posterior side, and poorly developed cristate tooth; lip formed at distal end of anterior septal chamber wall, and its proximal end attaching to cristate tooth, so that elongate loop-shaped appearance given externally (Pl. 25, fig. 12). Etched

wall showing IV Type structure.
Type and occurrence: – Holotype, Pl. 2, figs. 14a-c, IGPS 97235, sample OK–10 (A), Yonabaru Formation, Okinawa Island.
Remarks: – This new species, which is very rarely found in the Pliocene Yonabaru and Shinzato Formations, is characterized by its fusiform test with a slightly coiled early portion and an elongate loop-shaped aperture with poorly protruded cristate tooth (D6 Type).

In these features, this new species is comparable with the late Pleistocene or Rrecent species of *Cassidulinoides tenuis* Phleger and Parker, but the new species is dinstinct in having a non-slender test and non-inflated chambers.
Ontogeny and measurements: – Ontogenetic variation very slight.

IGPS	Sample	Length	Width	Thickness
97235 (Holotype)	OK–10(A)	0.68 mm	0.27 mm	0.20 mm

Occurrence in studied area: – Found rarely in samples OK–1, 4, 10(A), 21.
Previous record of occurrence: – Pliocene, Shinzato Formation, Okinawa Island, Japan (LeRoy, 1964).

Hastilina virga Nomura, sp. nov.

Pl. 2, figs. 15a–c

Cassidella bradyi (Cushman). Parker, 1964, p. 624, pl. 99, figs. 32, 33.

Description: – Test medium, much slender, slightly compressed on both sides, almost oval in cross section, very slightly curved, initial end sharp-pointed in microspheric form and narrowly rounded in megalospheric form, not lobulate; chambers distinct, but sometimes indistinct, last-formed chamber suboval in shape and making up last half of test in apertural side view, about four pairs biserially arranged, overlapped about half their length in peripheral margin; sutures very slightly curved toward periphery but almost straight, oblique to an axis of growth, somewhat depressed, not limbate; aperture subterminal, an elongate-loop obliquely extending upward from the base of apertural face, and almost to the apex of it, somewhat curved in megalospheric form; wall smooth, thin, very finely perforate, polished, and semiopaque.
Polarizing microscopy: – Wall mosaic-granular texture.
SEM observation: – Test microstructure of surface smooth, with calcitic microgranules. Pores slit-shaped on earlier formed chambers, but rounded on newly formed chambers; average length of slit-shaped pore 0.8 μm; average diameter of rounded pore 0.3 μm; pore density not determined. Inner structure showing copula without primary tongue attached to previous septal chamber wall in proximal end; cristate tooth indistinct. Etched wall section showing IV Type structure.
Type and occurrence: – Holotype, Pl. 2, figs. 15a-c, IGPS 97236A, sample OK-1, Yonabaru Formation, Okinawa Island; paratype, IGPS 97236B, the same sample.
Remarks: – Two forms of this species, only rarely found in the Pliocene Yonabaru Formation, may be recognized on the basis of its external appearance: One has a more slender test with a sharply pointed initial end, and elongate loop-shaped aperture (D Type), the other is characterized by elongate test with a bluntly rounded initial end, and slightly curved loop-shaped aperture (D8 Type). These features are related to the size of proloculus.

Hastilina virga closely resembles specimens figured by Parker (1964) who referred them to *Cassidella bradyi* (Cushman) (=*Virgulina bradyi* Cushman, 1922b). Particularly, the specimen shown by her in fig. 33 agrees well with the megalospheric form of *H. virga*. The present

writer, therefore, believes that Parker's form should be synonymous with this new species. The present species also resembles somewhat *Cassidulinoides* cf. *waltoni* figured by McCulloch (1977), but distinct in the shape of chambers and apertural characters.

The specific name is from the Latin *virga* meaning twig with reference to such a shape of the test.

Ontogeny and measurements: – Ontogenetic variation slight.

IGPS	Sample	Length	Width	Thickness
97236A (Holotype)	OK–1	0.58 mm	0.20 mm	0.15 mm
97236B (Paratype)	–	0.43	0.16	0.13

Occurrence in studied area: – Found in samples OK–1, 4, 7.

Previous record of occurrence: – Recent, off Guadalupe Island (Parker, 1964).

Genus *Cassidulina* d'Orbigny, emended

Cassidulina d'Orbigny, 1826, p. 282.

Type species: – *Cassidulina laevigata* d' Orbigny, 1826, p. 282, pl. 15, figs. 4, 5, model no. 41: Recent, ships's ballast of unknown provenance.

Emended diagnosis: – Test free, lenticular to compressed-oval, commonly biumbonate; periphery carinate to narrowly rounded; chambers broad to sublunate, biserially arranged and planispirally enrolled, with a set of short, tapering and overlapping end at periphery in last formed coil; sutures tangentially or radially arranged; wall calcareous, hyaline, perforate, optically granular in texture; surface smooth, polished; aperture curved narrow, elongate slit paralleling periphery at the base of apertural face with apertural plate closing most of it; toothplate absent.

Stratigraphic distribution: – Upper Eocene to Recent.

Remarks: – This genus has hitherto been known as the largest taxon in the Family Cassidulinidae; almost all biserially enrolled forms have been placed in this genus. This genus is characterized by its granular wall texture and the presence of apertural plate concealing the apertural foramen. The construction of apertural plate is quite different from that of apertural ridge which is typically visible in the genus *Paracassidulina* gen. nov.

Feyling-Hanssen and Buzas (1976) emended the definition of *Cassidulina*. According to them, both optically granular and radial wall textures are included in the *Cassidulina*, for reasons that such species as those having a typical *Cassidulina* aperture including *C. asanoi*, *C. cushmani*, and *C. delicata* are constructed of optically radial wall texture. As mentioned above, however, the apertural structure recognized as a plate-like lip is not a true plate or lip, but an apertural ridge. Therefore, these species can not be placed in the genus *Cassidulina*. The forms described under these generic names are included in *Takayanagia* gen. nov. in this paper.

Cassidulina (s.s.) and *Lernella* are closely allied with each other, but the former is differentiated from the latter in having an involutely coiled test.

The apertural plate changes in appearance, and is constructed on the posterior side of the aperture, presenting a feature of cristate tooth. This feature may indicate that *Cassidulina* is derived from *Globocassidulina*.

Two different types of wall texture are observed in this genus; one is jagged-granular texture (III Type), and the other is mosaic-granular texture (IV Type). However, these differences may not be so significant as to be of generic level.

This genus ranges from upper Eocene to Recent. In Japan, it has been recorded from Paleogene to Recent, although

their occurrences have not accurately been clarified.

Genus *Lernella* Saidova, 1975, emended

Lernella Saidova, 1975, p. 327, 328 (type, *L. auri* Saidova, 1975).

Type species: – *Cassidulina inflata* LeRoy, 1944, p. 37, pl. 4, figs. 30, 31: Miocene, Sumatra.

Emended diagnosis: – Test free, oval to elongate; periphery rounded; umbilicus closed; chambers broad to elongate, involutely coiled in early stage, later becoming uncoiled in a series of alternating arrangement and overlapping at periphery; sutures depressed to flush with surface; wall calcareous, finely perforate, optically granular in texture; surface smooth to rough; aperture an arcuate narrow slit, extending from the base of final chamber, with large apertural plate concealing most of it.

Stratigraphic distribution: – Miocene to Recent.

Remarks: – The definition of the genus *Lernella* given by Saidova (1975) is as follows (literally translated from Russian text): "Test involute, disc-shaped. Chambers low to high. Aperture interiomarginal, arch-shaped, arranged in the base of chamber of apertural face, concealed by plate. Plate adheres to peripheral border of the preceding chamber. Microstructure granular."

In her original description, Saidova selected her new species *L. auri* as the type species. As mentioned in the description of *L. inflata* (LeRoy), however, the present writer considers that *L. auri* is a junior synonym of *L. inflata* on the basis of their chamber arrangements, apertural characters, and granular wall texture; *L. inflata* therefore becomes the type species of this genus.

Since Saidova (*op. cit.*) somewhat broadly defined this genus, such involutely enrolled species as *C. corbyi* Cushman and Hughes (1925) and *C. tumida* Natland (1938) are included in this genus. However, none of them has a distinct apertural plate which conceals the apertural foramen.

Previously, this genus has been included in *Cassidulinoides* on the basis of an elongate test with uncoiled chamber arrangement, although the wall structure and apertural feature are quite different.

This genus ranges from the Oliocene to Recent. In Japan, this genus has been known from Paleogene to Pleistocene deposits on the Pacific side. The oldest stratigraphic record in Japan is reported by Murata (1961) as *Cassidulinoides yamagaensis* Asano and Murata from the Ashiya Group in northern Kyushu.

Lernella inflata (LeRoy), 1944

Pl. 2, figs. 9a–c; Pl. 24, figs. 4, 5

Cassidulina inflata LeRoy, 1944, p. 37, pl. 4, figs. 30, 31; LeRoy, 1964, p. F40, pl. 11, figs. 13, 14.

Cassidulinoides inflatus (LeRoy). Belford, 1966, p. 54, pl. 26, figs. 14–17, text-fig. 17, nos. 13, 14.

Evolvocassidulina aff. *E. inflata* (LeRoy). Eade, 1967, p. 432, 433, fig. 4, no. 3.

Lernella auri Saidova, 1975, p. 328, pl. 114, fig. 2.

Description: – Test subcircular to elongate in side view, oval in edge view, nearly one-half as thick as high; periphery broadly rounded, distinctly lobulate; chambers broadly oval, inflated, four or five pairs in last-formed coil; last four chambers may occupy about two-thirds of circumference of test; sutures distinct, depressed, gently curved on surface, U-shaped in section; aperture an curved-elongate slit at the base of last septal face, with a projecting apertural plate concealing most of it; wall smooth, polished, very finely perforate, translucent to opaque.

Polarizing microscopy: – Wall showing jagged-granular texture.

SEM observation: – Test microtopography smooth, covered with calcitic microg-

ranules on test surface. Pores rounded, numerous, and evenly distributed; average pore diameter 0.3 μm; pore density 16 pores per 20×20 μm^2. Inner structure showing well-developed apertural plate formed obliquely in periphery of preceding chamber wall (Pl. 24, fig. 4; Figs. 52, 53); surface of apertural plate smooth without pores, whereas numerous mammillae occurring on inner surface (Pl. 24, fig. 5); lip formed by turning over of septal chamber wall. Etched wall section showing III Type structure.

Type and occurrence: – Hypotype, Pl. 2, figs. 9a-c, IGPS 97239A, sample OK–5, upper Yonabaru Formation, Okinawa Island.

Remarks: – Diagnostic features of this species are inflated broad chambers, U-shaped depressed sutures, and aperture with a large apertural plate (H2 Type). Altough this species was originally placed in *Cassidulina*, it has been referred either to *Cassidulinoides* or *Evolvocassidulina*. Belford (1966) stated that apertural characteristics and internal structure of this species are similar to those of *Cassidulinoides bradyi* (=*Evolvocassidulina bradyi*). However, this species can not be assigned to *Cassidulinoides* which has radial wall texture as well as to *Evolvocassidulina* which possesses different apertural characters.

When the holotype figure of *L. auri* is consulted, however, there seems to be no solid foundation for separating *L. auri* from *L. inflata*. Concerning *L. auri*, Saidova (1975) described as follows: "Test small, lengthened, inflated, peripheral chamber rounded; three to four chambers in final whorl, and they gathered in umbilical region; sutures curved, depressed; aperture high, arcuate, concealed with apertural plate, attached to the peripheral border of penultimate chamber; microgranular structure, translucent." (translated from her Russian text).

Ontogeny and measurements: – In shape of test, ontogenetic variation slight. But apertural plate much reduced in younger stages (Fig. 51).

IGPS	Sample	Length	Width	Thickness	Fig. 51
97239–1	OK–5	0.21 mm	0.20 mm	0.15 mm	(1)
97239–2	–	0.23	0.20	0.17	(2)
97239–3	–	0.26	0.20	0.17	(3)
97239–4	–	0.35	0.27	0.17	(4)
97239–5	–	0.46	0.35	0.29	(5)
97239A	–	0.49	0.38	0.28	(6)

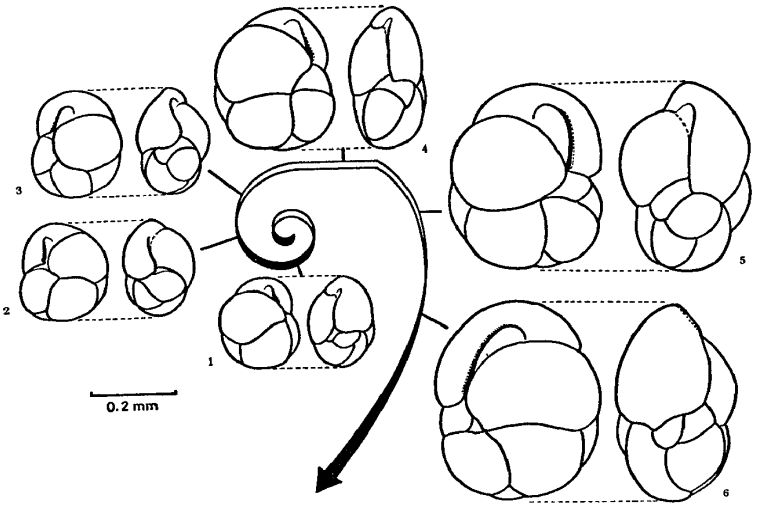


Fig. 51. Ontogeny of *Lernella inflata* (LeRoy).

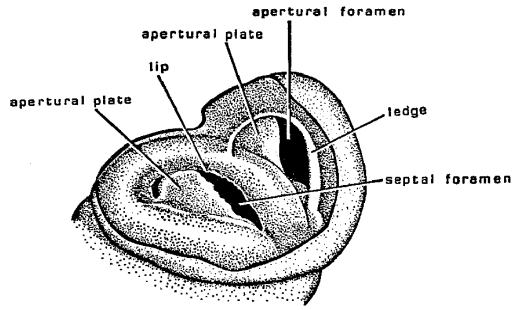


Fig. 52. Internal view of the final chamber of *Lernella inflata* (LeRoy).

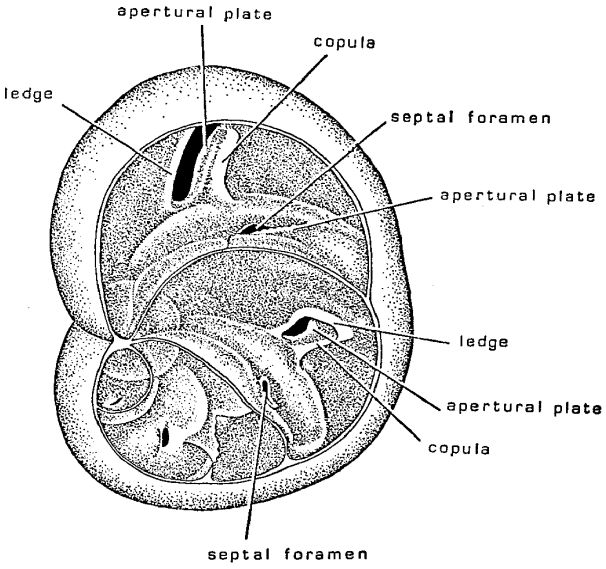


Fig. 53. Inner structure of *Lernella inflata* (LeRoy).

Occurrence in studied area: – Found in samples OG–13; CH–5, 6, 11, 13; BS–3, 7(A), 8, 10, 17; MU–1, 6, 11; MM–2; OK–1, 3, 4, 9, 10(A), (B), 12, 17, 19, 21, 23. The occurrences are restricted to the Pacific side of Japan.

Previous record of occurrence: – Middle Miocene, Sumatra, Indonesia (LeRoy, 1944); Pliocene, Yonabaru and Shinzato Formations, Okinawa Island, Japan (LeRoy, 1964); upper Miocene, New Guinea (Belford, 1966); Recent, off New Zealand (Eade, 1967).

Lernella ogasawarai Nomura, sp. nov.

Pl. 2, figs. 8a, b; Pl. 24, figs. 8, 9

Description: – Test medium, broadly oval in side view, elongate oval in edge view; periphery subacute to narrowly rounded, not lobulate; chambers distinct, not inflated, five pairs making up last-formed coil, very gradually increasing in size as added, tending to show a slight uncoiling in adult; sutures distinct, narrowly limbate, slightly curved toward the periphery but almost straight; aperture an arcuate narrow slit at the base of last-formed apertural face, with a distinct apertural plate concealing most of it and occupying major portion of apertural face; wall thin, smooth, polished, very finely perforate, translucent.

Polarizing microscopy: – Wall showing jagged-granular texture.

SEM observation: – Test microtopography smooth, and covered with calcitic microgranules. Pores numerous, rounded to elongate in shape (Pl. 24, fig. 9); rounded pores almost restricted to final chamber and narrow region near aperture; apertural plate, apertural face, and sutural regions imperforate; average pore diameter of elongate type 0.9 μm, rounded type 0.3 μm; pore density about 17 pores per $20 \times 20\ \mu m^2$. Inner structure showing apertural plate formed in periphery of preceding chamber wall, but posterior and anterior ends of its base connected with septal chamber wall. Etched wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 8a, b, IGPS 97241A, sample OK–13, Shinzato Formation, Okinawa Island.

Remarks: – This species is characterized by its subauriculate-compressed test with non-lobulate periphery, and H Type aperture with a crescent-shaped apertural plate. It somewhat resembles *Cassidulina kattoi* Takayanagi from the Ananai Formation of Kochi Prefecture in the apertural characters, but differs in having laterally more compressed

test and straight-radiate sutures.

It also resembles *Evolvocassidulina bradyi* (Norman), *E. orientalis* (Cushman), and *E. compacta* (Cushman and Ellisor), but *L. ogasawarai* can be distinguished from these species in having a semicircular apertural plate.

This new species is named after Dr. K. Ogasawara of the Institute of Geology and Paleontology, Tohoku University.

Ontogeny and measurements: – Ontogenetic variation slight (Fig. 54).

IGPS	Sample	Length	Width	Thickness	Fig. 54
97241–1	OK–13	0.24 mm	0.18 mm	0.14 mm	(1)
97241–2	–	0.28	0.21	0.15	(2)
97241–3	–	0.33	0.23	0.18	(3)
97241–4	–	0.34	0.28	0.18	(4)
97241A (Holotype)	–	0.35	0.27	0.16	

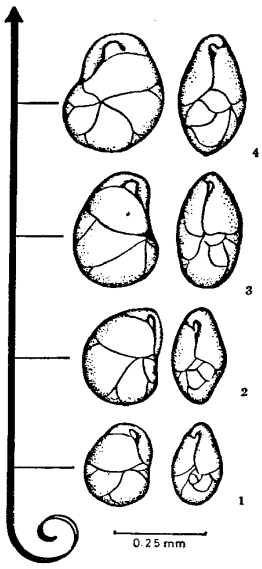


Fig. 54. Ontogeny of *Lernella ogasawarai* Nomura, sp. nov.

Occurrence in studied area: – Found in samples OK–1-4, 8, 13, 14, 19-23.

Genus *Burseolina* Seguenza, 1879, emended

Burseolina Seguenza, 1879, p. 138.
Cushmanulla Saidova, 1975, p. 336 (type, *Cassidulina pacifica* Cushman, 1925b).
Cassisphaerina Saidova, 1975, p. 336, 337 (type, *C. globula* Saidova, 1975).

Type species: – *Burseolina calabra* Seguenza, 1879, p. 138, p. 8, figs. 7a, b: Upper Miocene of Reggio, Calabria.

Emended diagnosis: – Test free, globular to suglobular in outline; periphery broadly rounded to angular; chambers low and broad, biserially enrolled throughout, gradually increasing in size as added, overlapped strongly on dorsal and ventral sides; sutures flush with surface; wall calcareous, optically granular in texture, finely perforate with slit-shaped to round; surface smooth or with coarse ridges and reticulations; aperture elongate, a bow-shaped narrow slit, extending up to the base of apertural face of final chamber at high angle, with distinct imperforate apertural flap on lower margin; toothplate indistinct, very poorly developed on upper margin of aperture.

Stratigraphic distribution: – Upper Eocene to Recent.

Remarks: – Seguenza (1879) considered this genus to be placed between *Pullenia* and *Nonionina* (=*Nonion*) in taxonomy. Subsequently, Brady (1884) placed it in *Cassidulina* after his examination of Seguenza's *B. calabra*, and referred his "Challenger" specimens to *C. calabra*. As beautifully illustrated and redefined by Loeblich and Tappan (1964a), however, *B. calabra* is different from Brady's *C. calabra* in having angular to carinate periphery and striated or reticulated surface. Nevertheless, close examination of *B. calabra* by Loeblich and Tappan (*op. cit.*) indicates that such important characters as enrolled chambers and apertural organization well coincide with those of *C. pacifica* Cushman. The forms having a globular test with a distinct apertural flap, which are previously

included in *Cassidulina* or *Globocassidulina*, are placed in *Burseolina* in this paper.

Saidova (1975) proposed a new genus *Cushmanulla* with *Cassidulina pacifica* Cushman as its type species. At the same time, she also proposed another new genus *Cassisphaerina*. Regarding the aperture of *Cassisphaerina*, Saidova (*op. cit.*) stated "aperture slit-shaped, curved, arranged perpendicularly to the base of apertural face. Upper side of aperture bends inward, chamber transfers to thin plate, which reaches to the base of preceding aperture." However, these apertural morphologies are another notable character of *Burseolina*. Therefore, the present writer treats Saidova's two genera *Cushmanulla* and *Cassisphaerina* as junior synonyms of *Burseolina*.

Globocassidulina is most closely allied to *Burseolina*. Although the characteristic difference exists between them in their mature forms, juvenile *Burseolina* is sometimes difficult to discriminate from some species of *Globocassidulina*, particularly those having the aperture of C or D Type. This feature probably indicates that *Burseolina* may have derived from *Globocassidulina*.

This genus has been known from late Eocene to Recent in the tropical and subtropical regions. In Japan, it has been reported from the Pliocene to Recent in the Pacific coast region, but has not been reported from the Japan Sea coast area.

Burseolina bullaeformis Nomura, sp. nov.

Pl. 2, figs. 10a–c, 11; Pl. 21, figs. 11, 12; Pl. 22, fig. 1

Description: – Test very small, nearly globular to subglobular in both front and side views, very slightly longer than broad; periphery broadly rounded, slightly lobulate; chambers in later portion distinct and broad, slightly inflated, about five pairs making up last-formed coil, increasing gradually in size as added; sutures of later portion distinct, narrowly limbate, gently curved, very slightly depressed; aperture elongate curved, almost paralleling to periphery of final apertural face, with a distinct apertural flap; wall smooth, polished, finely perforate, transparent.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth and covered with calcitic microgranules. Pores rounded, evenly distributed, and almost the same in size (Pl. 22, fig. 1); pore margin flush, but slightly depressed on inner surface; apertural flap and septal chamber wall imperforate; average pore diameter 1.8 μm; pore density nine pores per 20×20 μm^2. Aperture I1 Type (Pl. 21, fig. 11); cristate tooth and lip edged with b and c types (see Fig. 15); apertural ridge absent; inner structure showing copula attached to preceding apertural flap, forming narrow primary tongue and cavities (Pl. 21, fig. 12; Fig. 56); secondary tongue formed in previous whorl, particularly in mature chambers. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 10a-c, IGPS 97246A, sample BS–7 (A), Otadai Formation, Boso Peninsula; paratype, IGPS, 97246B, the same sample.

Remarks: – Diagnostic feature of this new species is its spherical and small test. The possession of rounded pores on all the chambers is also the notable character of this species, because other species of this genus have slit-shaped perforation in the early portion of the last whorl.

This new species resembles *B. pacifica* in its test shape and apertural characters. Particularly, its inner structure shows that the mode of development of tooth-plate is the same in both species. However, *B. bullaeformis* differs from *B. pacifica* in having a much smaller and thinly calcified test, and non-slit-shaped

pores.

The specific name is from the Latin *bulla* meaning a water bubble, referring to the small spherical test with transparent to translucent walls.

Ontogeny and measurements: – Ontogenetic variation is clearly displayed in the shape of aperture (Fig. 55).

IGPS	Sample	Length	Width	Thickness	Fig. 55
97246–1	BS–7(A)	0.14 mm	0.12 mm	0.11 mm	(1)
97246–2	–	0.15	0.14	0.13	(2)
97246–3	–	0.16	0.14	0.13	(3)
97246–4	–	0.15	0.13	0.14	(4)
97246–5	–	0.15	0.14	0.13	(5)
97246–6	–	0.19	0.14	0.15	(6)
97246–7	–	0.17	0.15	0.15	(7)
97246–8	–	0.19	0.15	0.15	(8)
97246–9	–	0.22	0.21	0.19	(9)
97246–10	–	0.24	0.21	0.19	(10)
97246A (Holotype)	–	0.25	0.22	0.20	

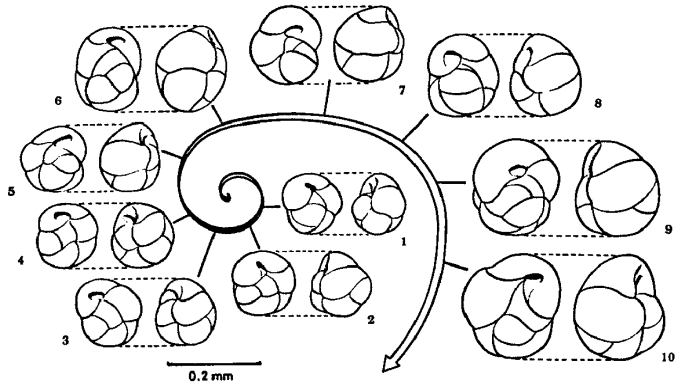


Fig. 55. Ontogeny of *Burseolina bullaeformis* Nomura, sp. nov.

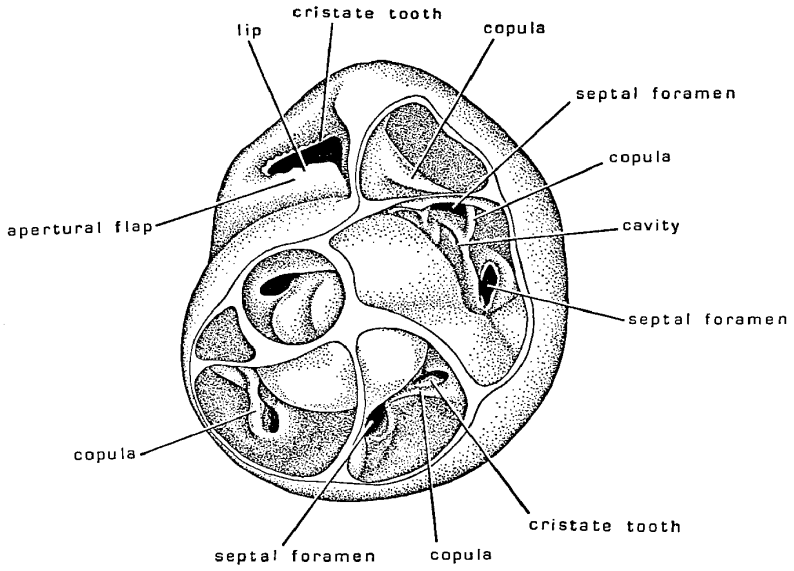


Fig. 56. Inner structure of *Burseolina bullaeformis* Nomura, sp. nov.

Occurrence in studied area: – Found in samples CH–1, 2, 4, 8, 12, 14-16. This species is common in Pleistocene deposits of the Pacific borderland.

Burseolina marshallana (Todd) *minima* Nomura, subsp. nov.

Pl. 2, figs. 12a, b, 13

Description: – Test small to medium, ellipsoidal in outline, somewhat compressed, nearly oval in apertural view; periphery broadly rounded; chambers distinct except for earlier portion, narrow and elongate, not inflated, about five to six pairs forming last coil, gradually increasing in size as added, and slightly prolonged; sutures distinct but obscure in early portion, very narrowly limbate, flush with surface, moderately curved; aperture an arched narrow slit, almost parallel to dorsal peripheral margin of apertural face with a distinct apertural flap concealing most of it, surrounded by a narrow depression, but anterior margin of apertural flap slightly swelled; wall smooth, polished, very finely perforate, initially translucent but becoming opaque toward early portion.

Polarizing microscopy: – Wall showing jagged-granular texture.

SEM observation: – Test microtopography smooth with calcitic microgranules. Pores on earlier portion slit-shaped, aligned in one direction, tending to become rounded toward later chambers; pore margin sightly depressed on inner surface; imperforate area restricted to apertural flap and apertural face; average diameter of rounded type 0.4 μm; length of slit type 2.0 μm; pore density four pores per $20 \times 20\ \mu m^2$. Aperture I2 Type with well-developed apertural flap; cristate tooth edged with c type (see Fig. 15); apertural ridge not present; inner structure showing copula attached to preceding apertural flap at a high angle; primary tongue indistinct in ephebic chambers, whereas in neanic stage very slightly separated; secondary tongue not formed. Etched wall section showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 12a, b, IGPS 97247A, sample OK–14, upper Yonabaru Formation, Okinawa Island; paratype, IGPS 97247B, the same sample.

Remarks: – The oval outline in apertural view and an arched narrow slit of aperture with a large apertural flap are diagnostic features of this new subspecies. Having these features, this subspecies is very similar to *Cassidulina marshallana* Todd, but differs in having a slightly invaginated wall below the aperture and much smaller size. Maximum diameter of *B. marshallana minima* is *ca.* 0.35 mm, whereas *B. marshallana* (s.s.) ranges from 0.55 to 1.10 mm.

The subspecific name refers to the size of the test.

Ontogeny and measurements: – As demonstrated in *B. pacifica*, the ontogenetic variation of the aperture is similar to that of *B. pacifica*.

IGPS	Sample	Length	Width	Thickness
97247A (Holotype)	OK–14	0.31 mm	0.24 mm	0.26 mm
97247B (Paratype)	–	0.30	0.19	0.20

Occurrence in studied area: – Very abundant in samples OK–4 and 14 from the Yonabaru Formation, especially abundant in OK–14.

Genus *Ehrenbergina* Reuss, 1850

Ehrenbergina Reuss, 1850, p. 377.

Type species: – *Ehrenbergina serrata* Reuss, 1850, p. 377, pl. 48, figs. 7a-c: Tertiary, Baden, near Vienna, Austria.

Diagnosis: – Test free, triangular to broadly oval in dorsal and ventral views, compressed perpendicular to a plane of coiling and slightly coiled in early portion, with peripheral spines; dorsal side flat to

convex, ventral side concave with or without median furrow; chambers compressed, low and broad, biserially arranged throughout, and overlapped on dorsal side; wall calcareous, finely perforate, optically granular in texture; surface smooth or with spines or ridges; aperture curved slit with toothplate, perpendicular to the base of apertural face and paralleling to dorsal side.

Stratigraphic distribution: – Eocene to Recent.

Remarks: – Loeblich and Tappan (1964a) erected a new genus *Reissia* based upon a Recent species *E. hystrix* (Brady) from the South Pacific. As already stated by Wood (1949), *E. hystrix* has been known to have radial wall texture. Despite of its test morphology quite similar to *Ehrenbergina*, the possession of radial wall texture was treated by Loeblich and Tappan (*op. cit.*) as a distinct character from the granular built *Ehrenbergina*. They also stressed that *Reissia* has a more complex toothplate and non-porous, radially grooved apertural face similar to that of *Buliminella*, following the observation of Hofker (1951b). Consequently, they placed *Reissia* in the Islandiellidae of the superfamily Buliminacea. The present writer agrees with their definition of this genus, however, it is difficult to accept their suprageneric classification in the following points.

1) Toothplate is usually present in the genus *Ehrenbergina*.

2) Such species as *Ehrenbergina bosoensis* and *E. crispata* sp. nov. have distinct apertural grooves. Therefore, the apertural grooves are not the only feature restricted to the genus *Reissia*.

3) Detailed examination of holotype figures of *E. hystrix*, the feature described by Hofker (1951b) as protruding toothplate on ventral side is equivalent to the present writer's apertural flap which is usually present in the ehrenberginid aperture.

For these reasons, the present writer considers that the genus *Reissia* should be placed in the family Cassidulinidae.

Hofker (1951b, 1956b) investigated the inner structure of some species of this genus and discussed the phylogenetic relationship on the basis of toothplate. He stated "*Ehrenbergina* is very closely related to *Cassidella* (partly *Fursenkoina*) and to its offspring *Cassidulina*." At preset, on the basis of degree of development of toothplate only, it is very difficult to determine whether Hofker's view is right or not. Because the shape of toothplate varies among different species even within the same genus. Many figures of inner structure given by Hofker are not fully illustrated and seem to be somewhat incorrectly interpreted. The protruded tooth on the ventral side of the aperture which seems to extend backward to the preceding aperture may be included in the toothplate in Hofker's sense. However, the present writer could not observe this feature in any species of Japanese *Ehrenbergina*. The toothplate is usually formed by infolding the dorsal side wall, and glued to the preceding lip at the proximal end and to a newly formed ventral wall at the distal end of the aperture. The toothplate is almost concealed by the apertural flap of ventral wall.

Ehrenbergina is closely allied to *Burseolina* in the shape and position of aperture which is opened at a high angle to the axis of symmetry of test and almost parallel to the periphery, but *Ehrenbergina* differs from *Burseolina* in having non-involute chambers.

Ehrenbergina has commonly been found from Eocene to Recent deposits. In Japan, this genus is common in the Miocene to Recent, whereas Paleogene species has not been recorded as yet.

Ehrenbergina crispata Nomura, sp. nov.

Pl. 2, figs. 18a, b; Pl. 23, fig. 5

Description: – Test medium, rounded-rhobmic in both ventral and dorsal views,

compressed and nearly semi-ellipsoidal in side view, with narrowly rounded apical end; dorsal side convex, ventral side concave with indistinct median furrow; periphery acute to subacute, distinctly lobulate; chambers low and broad, not inflated, biserially arranged throughout, about five to six pairs, last-formed chamber compressed, branchial shape in appearance; sutures distinct except for early portion, dorsal sutures depressed toward periphery, moderately curved, ventral sutures strongly depressed in periphery, particularly more distinct in later; aperture subterminal, narrow slit, semi-circular in outline, provided with distinct apertural flap bordered by narrow lip; wall translucent, finely perforate, ornamented by moderate undulation except for last few chambers, last formed apertural face with numerous grooves arranged in a radial manner, but not visible in apertural flap.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test surface moderately undurate; microtopography smooth, coated by calcitic microgranules; apertural grooves U-shaped in cross section. Pores rounded, but not present on apertural flap and sutural regions; average pore diameter 0.8 μm; pore density not determined. Inner structure showing I Type aperture (Pl. 23, fig. 5); structure of toothplate almost identical with that of other species of this genus; apertural flap somewhat spatulate in shape. Etched wall showing III Type structure.

Type and occurrence: – Holotype, pl. 2, figs. 18a, b, IGPS 97252, sample OK–1, Yonabaru Formation, Okinawa Island.

Remarks: – This new species, rarely found in samples from the Yonabaru and Shinzato Formations in Okinawa Island, is characterized by a rounded-rhomboid test, plicated appearance of the last pair of chambers, and semi-circular apertural flap.

In these features, this new species is quite different from other previously described ehrenberginid species.

The specific name is referred to the surface structure of the test.

Ontogeny and measurements:

IGPS	Sample	Length	Width	Thickness
97252 (Holotype)	OK–1	0.37 mm	0.32 mm	0.15 mm

Occurrence in studied area: – Found in samples OK–1, 4, 19, 20.

Genus *Paracassidulina* Nomura, gen. nov.

Type species: – *Cassidulina orientale* Cushman, 1925a, p. 37, pl. 7, figs. 6a-c (= *Globocassidulina nipponensis* Eade, 1969, p. 65, 66, pl. 13, figs. 1–4); Recent, Nero station 1264, south of Japan.

Diagnosis: – Test free, compressed, circular to subauriculate in side view; periphery narrowly rounded; umbilicus commonly closed; chambers biserially arranged and enrolled as in *Cassidulina*, sometimes uncoiling in later, but continuing biserial development, increasing in size as added and overlapped at periphery; sutures commonly flush with surface, sometimes distinctly depressed; wall calcareous, finely perforate, optically granular in texture; surface smooth, polished to dimly reflected, with or without irregularly distributed grooves; aperture an interiomarginal, long and narrow slit, parelleling to periphery of preceding chamber.

Stratigraphic distribution: – Upper Cretaceous (?) to Recent.

Remarks: – *Paracassidulina* gen. nov. is characterized by its granular wall texture and interiomarginal aperture of an elongate and narrow slit without toothplate (G Type).

An observable variation of the aperture of this genus is very slight and most stable during the ontogenetic dvelopment. On the other hand, two main forms – circular

one having planispirally enrolled chambers and subauriculate one having a tendency to uncoil — are apparently recognized in the test shape. The latter form has been included in *Cassidulinoides* Cushman by many workers. These two forms, however, show a continuous morphological series, such as the one known for *P. sagamiensis* (Asano and Nakamura). Therefore, these two forms can not be separated on the basis of coiling pattern only.

The limited resolution power of optical microscope leads to some confusion especially as to the recognition of an apertural ridge which is usually present in this genus. As stated in the remarks of *Cassidulina* and in the earlier portion of this paper, the apertural ridge is not equivalent to the apertural plate in morphology as well as in nature.

Paracassidulina most closely resembles *Takayanagia* gen. nov. in having identical apertural characters and inner structure. However, *Takayanagia* differs from the former in possessing a typical hyaline test with the distinctly radial wall texture.

The stratigraphic range of this genus may be the longest among the cassiduline forms, and its geologic occurrence presents serious difficulties in assuming the kind of form from which this genus has evolved. *Cassidulina cretacea* Cushman from the upper Cretaceous may be placed in this genus. In Japan, this genus has been reported from Miocene to Recent sediments as *Cassidulina*.

Paracassidulina nipponensis (Eade), 1967

Pl. 25, figs. 3

Cassidulina orientale Cushman, 1925a, p. 37, pl. 7, figs. 6a–c; Asano and Nakamura, 1937a, p. 147, pl. 14, figs. 6a, b; Asano, 1951, pt. 7, p. 2, figs. 9, 10; Matsunaga, 1963, pl. 48, figs. 7a, b; LeRoy, 1964, p. F40, pl. 11, figs. 15, 16.

Globocassidulina nipponensis Eade, 1967 (part), p. 65, pl. 13, figs. 1a–c, 2a–c, 4 (not fig. 3).

Not *Cassidulinoides orientale* (Cushman). Barker, 1960, p. 112, pl. 54, figs. 10a–c.

Description: – Test compressed, broadly oval to subauriculate in side view, both sides parallel in edge view; periphery compressed-rounded, not lobulate; chambers distinct, not inflated, five to six pairs in last-formed coil, tending in adult specimens to show uncoiling; sutures distinct, nearly straight, flush with surface; aperture an elongate narrow slit parallel to periphery at the base of last apertural face; wall very finely perforate, polished, translucent to opaque.

Polarizing microscopy: – In polarized light, tangential sections revealing chamber walls constructed of minute granular; in apertural ridges, tiny flecks of color somewhat larger than those of chamber walls. Wall jagged-granular texture.

SEM observation: – Test microtopography smooth; calcitic microgranules observed on outer and inner test surface. Pores small, slit-shaped, arranged in one direction in earlier chambers; average pore length 0.5 μm; pore density not determined. Inner structure showing no toothplate (Pl. 25, fig. 3; Fig. 57); posterior end of apertural ledge attaching to preceding septal chamber wall, and anterior end reaching early formed chamber wall; apertural ridge distinct. Etched wall showing III Type structure.

Remarks: – This species was originally described by Cushman (1925a) from Recent marine sediments off southern Japan under the name of *Cassidulina orientale*.

Two forms of *P. nipponensis* can be recognized on an external appearance. One megalospheric form having a large and broad oval test with the B type coiling (see Fig. 9), closely resembles the figure given by Asano and Nakamura (1937a) and Asano (1951); the other, which is microspheric form having a much compressed subauriculate test with the C type coiling (see Fig. 9), resembles the holotype figure of Cushman (1925a).

These two species are characterized by a long narrow slit-like aperture with a thin apertural ridge and non-depressed sutures.

Eade (1969) discussed taxonomic problems of this species, and gave a new name *nipponensis* under the genus *Globocassidulina* on the ground that the original specific name (*Cassidulina orientale*) represents a separate species, *Cassidulina orientalis* Cushman (1922b) (=*Evolvocassidulina orientalis*). Although the original description made by Cushman (1925a) well agrees with the present species, Eade also remarked on ontogenetical variations of apertural characters as follows: "the aperture in the juvenile is trifid.... The areal portion of the aperture is moderately short in the juvenile but only just discernible in the adult". This feature is shown well in his figures of the specimen. However, anatomical observations of this species show that the mode of ontogenetic development of apertural type is not variable except for the proloculus bearing a rounded aperture, and not a tripartite but a narrow slit parallel to the base of apertural face in each ontogenetic stage (Pl. 25, fig. 3; Fig. 57). The present writer therefore believes that the form presented by Eade (*op. cit.*) may be a different species and does not represent juveniles of the present species.

The microspheric form of this species differs from *P. oshimai* in having a larger test.

Ontogeny and measurements: – Neanic specimens rounded in side view, but showing tendency to uncoil in ephebic stage.

IGPS	Sample	Length	Width	Thickness
(microspheric forms)				
97411–1	MM–5	0.24 mm	0.18 mm	0.12 mm
97411–2	–	0.27	0.21	0.12
97411–3	–	0.27	0.17	0.10
97411–4	–	0.33	0.22	0.11
97411–5	–	0.36	0.26	0.12
97411–6	–	0.36	0.24	0.11
97411–7	–	0.39	0.28	0.13
97411–8	–	0.40	0.27	0.13
(megalospheric form)				
97267–1	MM–5	0.54	0.41	0.22

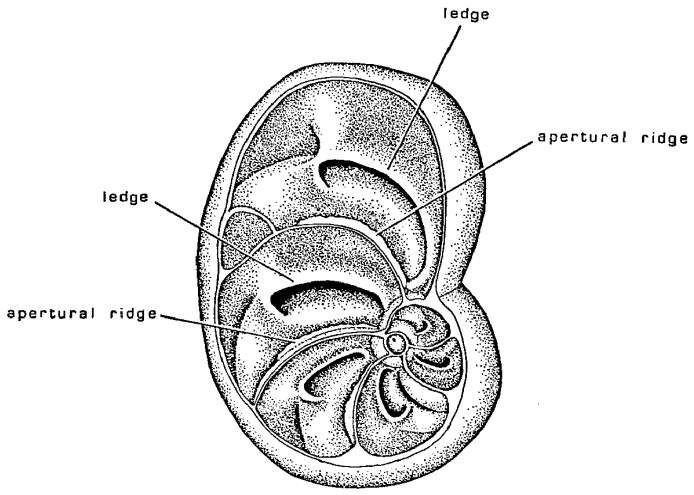


Fig. 57. Inner structure of *Paracassidulina nipponensis* (Eade), gen. nov.

Occurrence in studied area: – Found in samples OK–8, 9, 14, 21; BS–5, 10; MU–1, 2, 4, 6, 9; MM–1, 5, 6; KM–52, 53; OG–13, 21; ST–2, KR–5.
Previous record of occurrence: – Recent, off southern Japan (Cushman, 1925a); Ushigakubi Formation, Niigata Prefecture, Japan (Matsunaga, 1963); Pliocene, Yonabaru and Shinzato Formations, Okinawa Island, Japan (LeRoy, 1964). Mostly known from Pliocene to Recent on the Pacific coast of Japan.

Paracassidulina nipponensis (Eade) *terebra* Nomura, subsp. nov.

Pl. 2, figs. 20a, b; Pl. 25, fig. 8

Description: – Test medium, compressed, broadly oval to subcircular in side view, both sides parallel in edge view; periphery compressed-rounded, not lobulate; chambers distinct, broad, not inflated, five pairs in last coil, tending to show uncoiling in final growth stage; sutures distinct, limbate, radially slightly curved toward periphery, but almost straight, not depressed; aperture an elongate narrow slit parallel to periphery at the base of final apertural face, occupied two-thirds of apertural face; wall distinctly perforate, somewhat diffusely reflected, translucent to opaque.
Polarizing microscopy: – Wall jagged-granular texture.
SEM observation: – Pores relatively coarse and pore margin very slightly depressed, slit to narrow elongate (Pl. 25, fig. 8), and randomly arranged in antipenultimate chamber wall; average pore length 3.3 μm; pore density 26 pores per $25\times25\ \mu m^2$; pores on final chamber more smaller and rounded; apertural face and sutural region imperforate. Apertural ledge attaching to preceding apertural face on posterior side and to earlier formed chamber wall on anterior side; pseudolip indistinct; apertural ridge thinly protruded. Sectioned and etched specimens, wall showing III Type structure.
Type and occurrence: – Holotype, Pl. 2, figs. 20a, b, IGPS 97412, sample BS–6, Kiwada Formation, Boso Peninsula; paratype, IGPS 97412A, the same sample.
Remarks: – This new subspecies occurs commonly in a fossiliferous sandstone of the lower Pleistocene Kiwada and Otadai Formations of the Boso Peninsula, but its distribution is restricted to the above-mentioned area. Slit-shaped or irregular perforations are the most notable feature of this subspecies.

This subspecies is closely allied to the megalospheric form of *P. nipponensis* (Eade) in its test shape and inner structure, but their distributional patterns and type of perforations are somewhat different. *P. nipponensis terebra* also resembles *P. sagamiensis*, but differs in having non-inflated chambers, absence of apertural grooves, and non-lobulate periphery.

The subspecific name is the Latin *terebro*, meaning perforate or pierce, referring to the perforation of test.
Ontogeny and measurements: – In the early ephebic stage, this subspecies somewhat inflated, but fully matured specimens having more flat edge view.

IGPS	Sample	Length	Width	Thickness
97412–1	BS–6	0.23 mm	0.19 mm	0.13 mm
97412–2	–	0.27	0.21	0.14
97412–3	–	0.37	0.27	0.17
97412A (Paratype)	–	0.40	0.34	0.20
97412 (Holotype)	–	0.44	0.34	0.20

Occurrence in studied area: – Found in samples BS–6, 7 (A), (B).

Paracassidulina nabetaensis Nomura, sp. nov.

Pl. 2, figs. 16a, b; Pl. 5, fig. 5; Pl. 25, fig. 7

Description: – Test medium, elongate, curved, compressed, subauriculate in side view, circulo-linear in edge view; periphery narrowly rounded, lobulate; chambers distinct, moderately inflated, suboval in general shape, closely coiled in early portion, but uncoiled and much inflated in final growth stage, about six pairs in last coil; sutures distinct, somewhat curved toward periphery, depressed, U-shaped in section; aperture with shallow apertural grooves running out of aperture, parallel to suture at the base of apertural face in form of long narrow slit; wall smooth, polished, very finely perforate, translucent.

Polarizing microscopy: – Wall jagged-granular texture.

SEM observation: – Test microtopography smooth. Pores small, rounded to elongate; pore diameter of elongate type 0.9 μm, rounded type 0.2 μm; pore density 14 pores per 20×20 μm^2; apertural face imperforate. Inner structure showing no toothplate (Figs. 59, 60); apertural ledge attaching to preceding septal chamber wall on posterior end and to earlier formed chamber wall in anterior end; aperture slit-shaped throughout ontogeny; apertural ridge formed in the periphery of preceding chamber; pseudolip not obviously developed. Etched wall showing III Type structure. Organic layer in final chamber wall only observed on outer side near sutures, but not developed in all portions of final one.

Type and occurrence: – Holotype, Pl. 2, figs. 16a, b, IGPS 97406, sample, Recent beach sand of Nabeta cove, Shimoda, Izu Peninsula.

Remarks: – This new species is characterized by a lobulate periphery and moderately inflated chambers. Because of these features, this species is alled to *Paracassidulina miuraensis* originally described from the Koshiba Formation of the Miura Peninsula, but differs in having a more thickened test, inflated chambers, and lobulate periphery. Another species similar to *P. nabetaensis* is *P. nipponensis*. *P. nipponensis* differs in not having sutural grooves and lobulate periphery.

This species is named after the geographic name of its type locality.

Ontogeny and measurements: – Ontogenetic variation slight (Fig. 58).

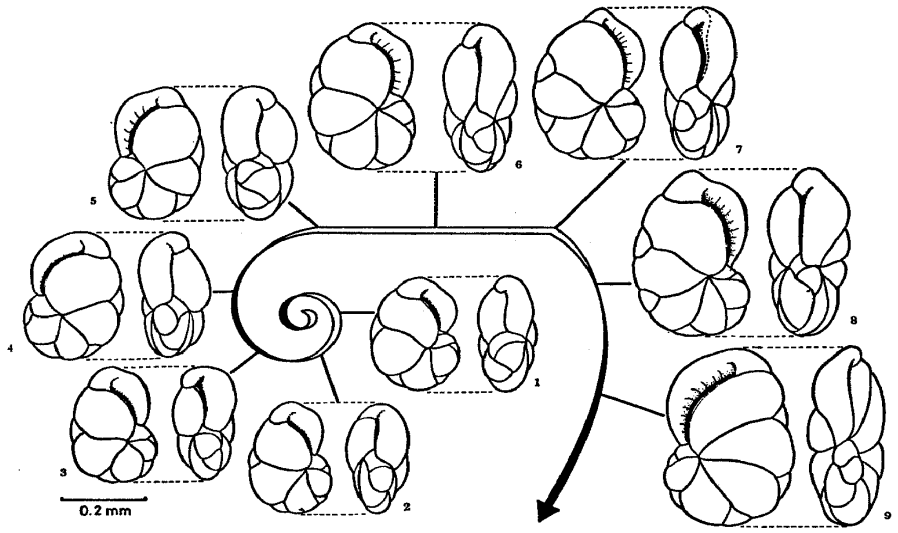


Fig. 58. Ontogeny of *Paracassidulina nabetaensis* Nomura, gen. et sp. nov.

IGPS	Sample	Length	Width	Thickness	Fig. 58
97406–1	Nabeta cove	0.29 mm	0.21 mm	0.14 mm	(1)
97406–2	–	0.29	0.19	0.15	(2)
97406–3	–	0.30	0.20	0.15	(3)
97406–4	–	0.33	0.24	0.17	(4)
97406–5	–	0.34	0.23	0.18	(5)
97406–6	–	0.36	0.25	0.17	(6)
97406–7	–	0.39	0.26	0.17	(7)
97406–8	–	0.42	0.28	0.20	(8)
97406–9	–	0.46	0.30	0.18	(9)
97406 (Holotype)	–	0.46	0.30	0.20	

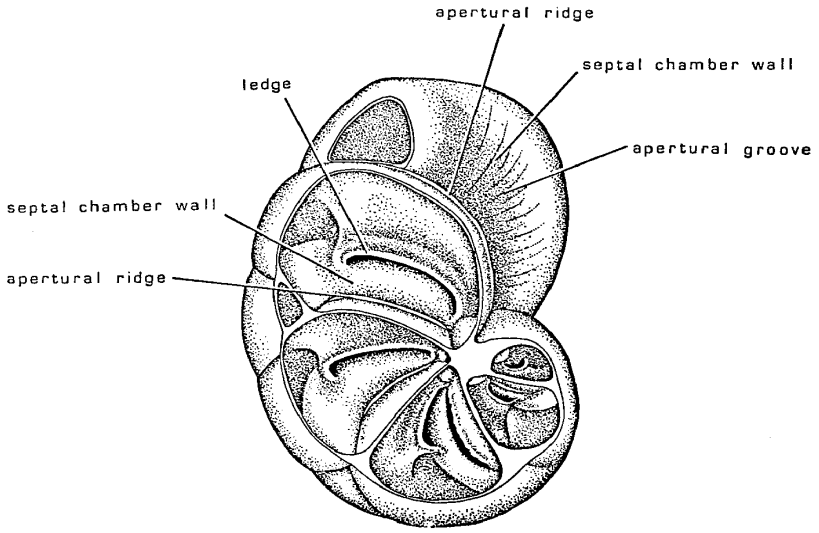


Fig. 59. Inner structure of *Paracassidulina nabetaensis* Nomura, gen. et sp. nov.

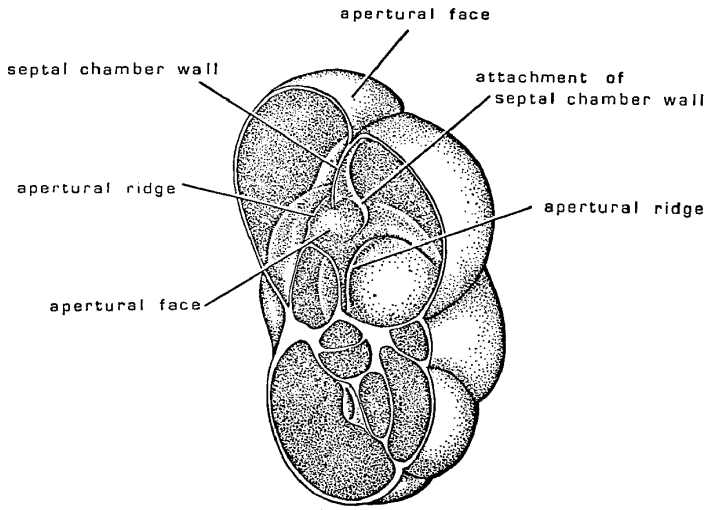


Fig. 60. Inner structure of *Paracassidulina nabetaensis* Nomura, gen. et sp. nov.

Occurrence in studied area: – Typical form known only from the type locality; somewhat varied forms found in the following samples OG–18, 19; NDU–17; KM–51, 52; CH–8; BS–1, 2, 4-6, 10, 17; MM–1, 3, 4; OK–4, 5, 7, 14, 19, 20, 22, 23.

Paracassidulina quasicarinata Nomura, sp. nov.

Pl. 2, figs. 19a–c; Pl. 25, figs. 9, 10, 11

Description: – Test medium, nearly circular in side view, compressed-lenticular in edge view; periphery lobulate, subacute; chambers distinct, tangentially curved, slightly inflated, particularly in periphery, about four pairs making up last-formed coil; umbilical region showing translucent to semi-opaque shell material, but earlier chambers of previous whorl not visible; sutures distinct, but obscure near umbilical region, gently curved toward periphery, and depressed; aperture an elongate narrow slit following the curve of preceding chamber, usually with thin apertural ridge and a few short very fine shallow grooves radiating from proximal end of aperture; wall thin, smooth, polished, very finely perforate, translucent.

Polarizing microscopy: – Wall showing jagged-granular texture.

SEM observation: – Test microtopography smooth; inner and outer test surfaces covered with calcitic microgranules. Pores slit-shaped; average length of slit-shaped pores 1.2 μm; pore density 13 pores per 20×20 μm^2; on inner test surface, pores rounded, with small pore swell evenly distributed, diameter 0.7 μm, width of pore swell 1.7 μm. Inner structure showing slit-shaped aperture throughout ontogeny; posterior end of apertural ledge attaching to preceding septal chamber wall (Pl. 25, fig. 9), and anterior and of it attaching to earlier formed chamber wall; pseudolip not observed; low apertural ridge formed in the periphery of preceding chamber wall (Pl. 25, figs. 9, 11). Etched wall showing III Type structure.

Type and occurrence: – Holotype, Pl. 2, figs. 19a-c, IGPS 97254A, sample MU–1, Nojima Formation, Miura Peninsula; paratype, 97254B, the same sample.

Remarks: – This species is characterized by its lobulate and subacute periphery, translucent umbilical region, and an apertural grooves at the proximal end of aperture.

In a narrow apertural slit with a thin ridge and chamber arrangement, the present species closely resembles *Paracassidulina neocarinata* (Thalmann), but differs from the latter in having a non-carinate periphery and a few apertural grooves running out of the proximal end of aperture. This new species also closely resembles *C. quasisulcata* Belford (1966) from the uppermost Miocene and Pliocene of New Guinea in having fine shallow grooves at the apertural margin, but is distinguished by its tangentially arranged more curved chambers, wide umbilical region filled with translucent shell materials, and more lobulate periphery. *Cassidulina* (?) *pilasensis* McCulloch (1977) is another closely comparable species, but *P. quasicarinata* is distinct in possessing the translucent umbilical area.

Ontogeny and measurements: – Ontogenetic variation slight.

IGPS	Sample	Length	Width	Thickness
97254–1	MU–1	0.13 mm	0.11 mm	0.06 mm
97254–2	–	0.14	0.13	0.08
97254–3	–	0.16	0.13	0.09
97254–4	–	0.18	0.14	0.09
97254–5	–	0.21	0.18	0.09
97254–6	–	0.22	0.18	0.12
97254–7	–	0.23	0.19	0.10
97254–8	–	0.23	0.18	0.10
97254–9	–	0.26	0.22	0.11
97254–10	–	0.28	0.23	0.13
97254–11	–	0.30	0.24	0.11

97254–12	–	0.30	0.27	0.14
97254A (Holotype)	–	0.33	0.30	0.12
97254B (Paratype)	–	0.38	0.36	0.15

Occurrence in studied area: – Found in OK–2, 8, 9-21. samples BS–6, 7(A), (B), 15; MU–1, 6;

Plate 1

Fig. 1a–c. *Islandiella compressa* Nomura, sp. nov. ..... p. 49
IGPS 97167, sample ST–2, Setana Formation, Hokkaido, ×55.

Figs. 2a–c. *Islandiella islandica* (Nørvang). ..... p. 47
IGPS 97153A, sample OG–20, Wakimoto Formation, Oga Peninsula, ×75.

Figs. 3a-c. *Takayanagia delicata* (Cushman). ..... p. 53
IGPS 97184, sample BS–16, Kokumoto Formation, Boso Peninsula, ×85.

Figs. 4a–c. *Cassidulinoides subcylindricus* Nomura, sp. nov. ..... p. 51
IGPS 97182A, sample AR–6, Tanihama Formation, Niigata Prefecture, ×75

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IGPS 97190A, sample OK–1, Yonabaru Formation, Okinawa Island, ×46.

Figs. 6a, b. *Globocassidulina parviapertura* Nomura, sp. nov. ..... p. 56
IGPS 97187, sample OK–18, Yonabaru Formation, Okinawa Island, ×46

Figs. 7a–c, 8. *Globocassidulina venustas* Nomura, sp. nov. ..... p. 60
7–IGPS 97224, sample MU–1, Nojima Formation, Miura Peninsula, ×98; 8-scanning electron micrograph, ×100.

Figs. 9a–c, 10a, b. *Globocassidulina crenulata* Nomura, sp. nov. ..... p. 60
9–IGPS 97191A, sample OK–4, Shinzato Formation, Okinawa Island, ×75; 10-scanning electron micrograph, ×100.

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IGPS 97197, sample OK–17, Shinzato Formation, Okinawa Island, ×60.

Figs. 12a–c, 13. *Globocassidulina mucronata* Nomura, sp. nov. ..... p. 63
12–IGPS 97195A, sample OK–19, Shinzato Formation, Okinawa Island, ×55; 13–scanning electron micrograph, ×100.

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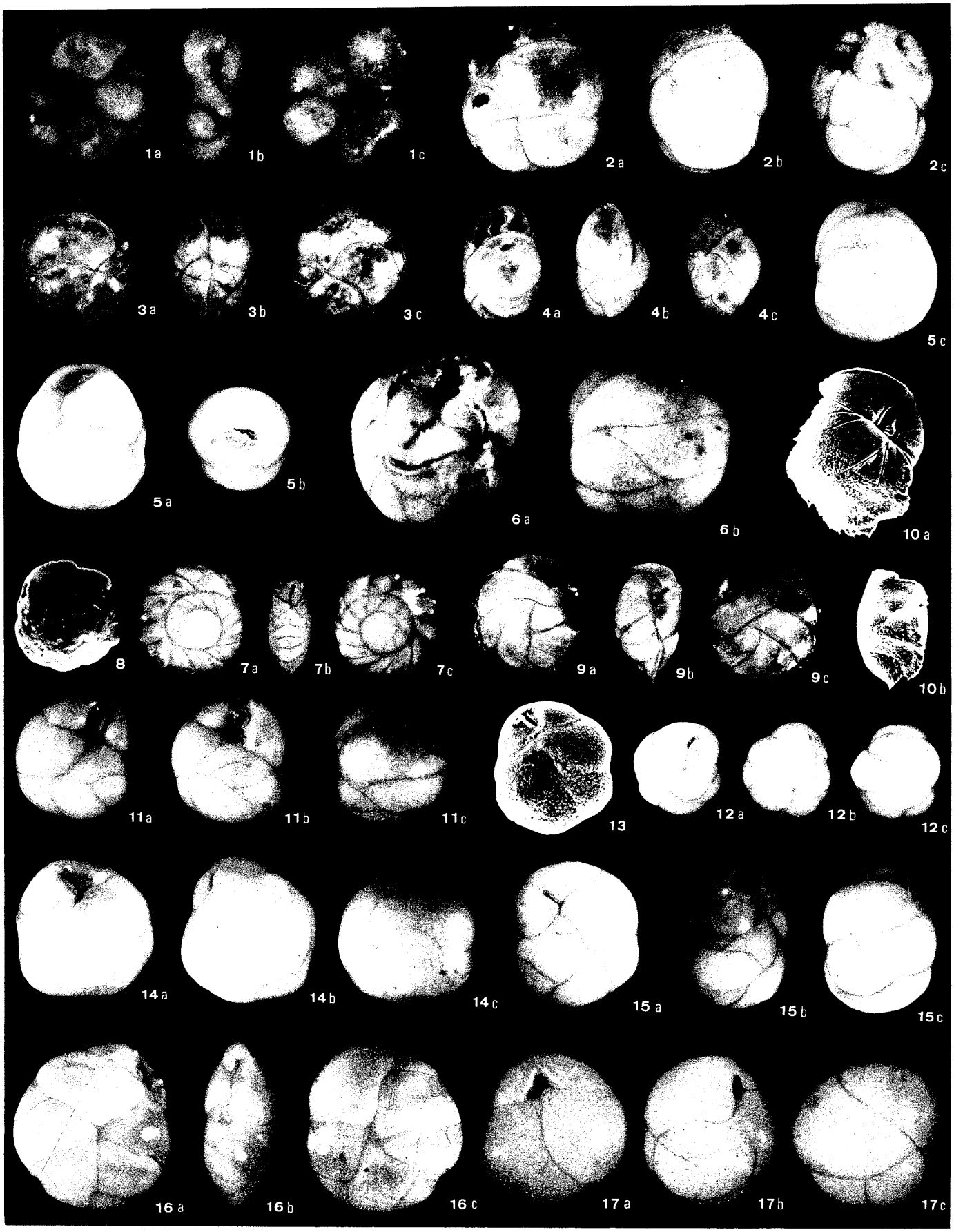
IGPS 97194A, sample OK–22, Shinzato Formation, Okinawa Island, ×70.

Figs. 15a–c. *Globocassidulina matobai* Nomura, sp. nov. ..... p. 65
IGPS 97198A, sample BS–2, Tomiya Formation, Boso Peninsula, ×70.

Figs. 16a–c. *Globocassidulina neobrocha* Nomura, sp. nov. ..... p. 67
IGPS 97206, sample BS–17, Yabu Formation, Boso Peninsula, ×60.

Figs. 17a–c. *Globocassidulina subbisecta* Nomura, sp. nov. ..... p. 68
IGPS 97212A, sample OK–3, Yonabaru Formation, Okinawa Island, ×75.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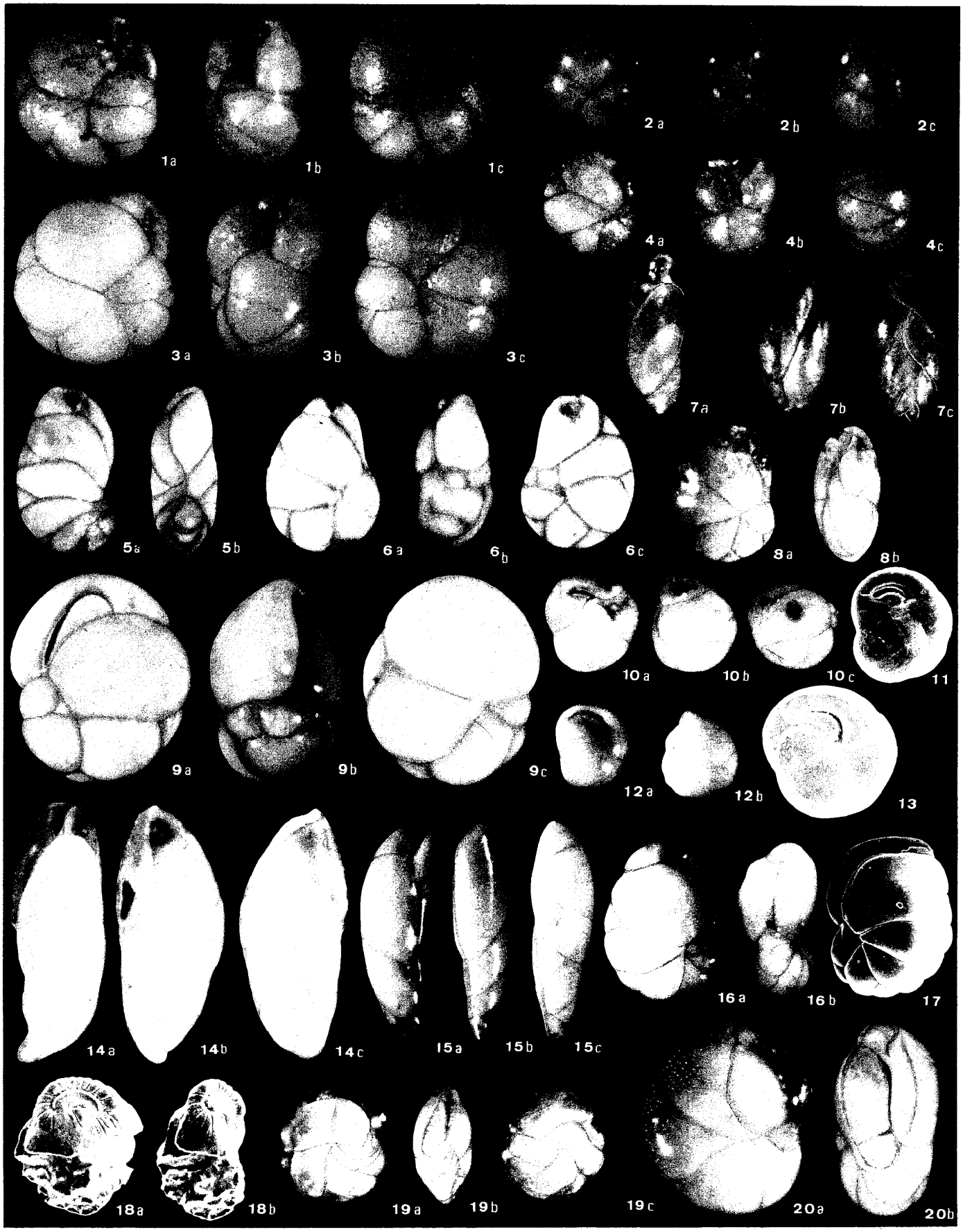
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Plate 2

Figs. 1a–c. *Globocassidulina rugosa* Nomura, sp. nov. ..... p. 71
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2–IGPS 97220A, sample BS–9, Kokumoto Formation, Boso Peninsula, ×60; 3–IGPS 97221, sample SW–3, Shichiba Formation, Sado Island, ×60.

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IGPS 97227, sample OK–15, Yonabaru Formation, Okinawa Island, ×60.

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Figs. 7a–c. *Hastilina mexicana* (Cushman). ..... p. 82
IGPS 97233, sample OK–16, Yonabaru Formation, Okinawa Island, ×70.

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12–IGPS 97247A, sample OK–14, Yonabaru Formation, Okinawa Island, ×56; 13-scanning electron micrograph, ×70.

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IGPS 97235, sample OK–10(A), Yonabaru Formation, Okinawa Island, ×70.

Figs. 15a–c. *Hastilina virga* Nomura, sp. nov. ..... p. 84
IGPS 97236A, sample OK–1, Yonabaru Formation, Okinawa Island, ×70.

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16–IGPS 97406, sample, Recent beach sand, Nabeta cove, Izu Peninsula, ×65; 17-scanning electron micrograph, ×70.

Figs. 18a, b. *Ehrenbergina crispata* Nomura, sp. nov. ..... p. 93
IGPS 97252, sample OK–1, Yonabaru Formation, Okinawa Island, ×70.

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Plate 3

Fig. 1. *Islandiella yabei* (Asano and Nakamura).
Fragment of test wall, showing distinctly radial texture. Sample ST–6, crossed nicols. ×600

Fig. 2. *Islandiella norcrossi* (Cushman).
Fragment of test wall, showing distinctly radial texture. Note completely extinguished darker area. Sample OG–20, crossed nicols. ×400

Fig. 3. *Islandiella wakasaensis* (Asano and Nakamura).
Fragment of test wall, showing indistinctly radial texture. Sample, Recent sediments off Rumoi, Hokkaido, crossed nicols. × 400.

Fig. 4. *Hastilina mexicana* (Cushman). .....p. 82
Fragment of test wall, showing mosaic-granular texture. Sample OK–16, crossed nicols. ×600.

Fig. 5. *Cassidulina carinata* Silvestri.
Fragment of test wall, showing jagged-granular texture. Sample OK–20, crossed nicols. ×600.

Fig. 6. *Islandiella setanaensis* (Asano and Nakamura). Etched and fractured cross section, showing curved crystal elements and continuous growth of tabular microcrystals indicative of rhombohedral cleavage. Note that each crystal unit composed of the same crystallographic orientation, but branching crystal elements differentiated from that orientation. Sample ST–1, treated with NaOCl. Electron micrograph, ×7500.

Fig. 7. *Islandiella sublimbata* (Asano and Nakamura).
Etched and fractured cross section, showing penultimate chamber wall. Note bundle-shaped crystal unit (CU) and crystal elements (CE). Sample ST–3, treated with NaOCl. Electron micrograph, ×10000.

Fig. 8. *Hastilina subtenuis* Nomura, sp. nov. .....p. 83
Polished and etched cross section, showing clumpy crystalline structure. Note crystal elements not much intricated. Sample OK–10(A), treated with Glutaraldehyde-phosphoric acid solution. Electron micrograph, ×4500.


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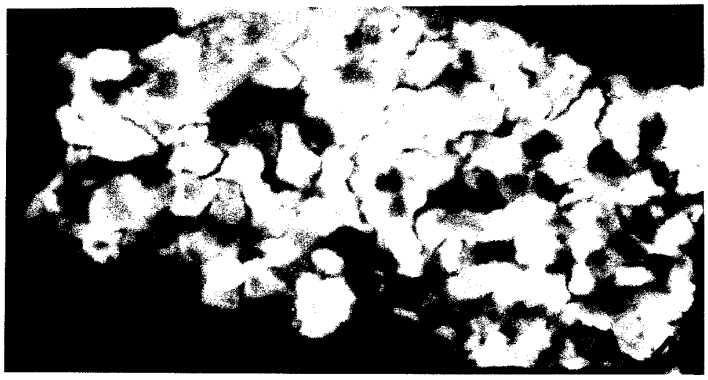


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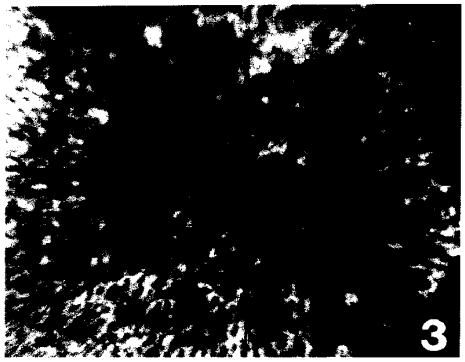
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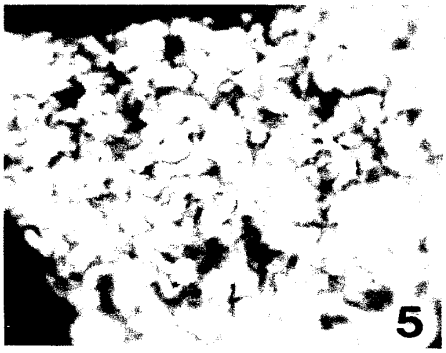
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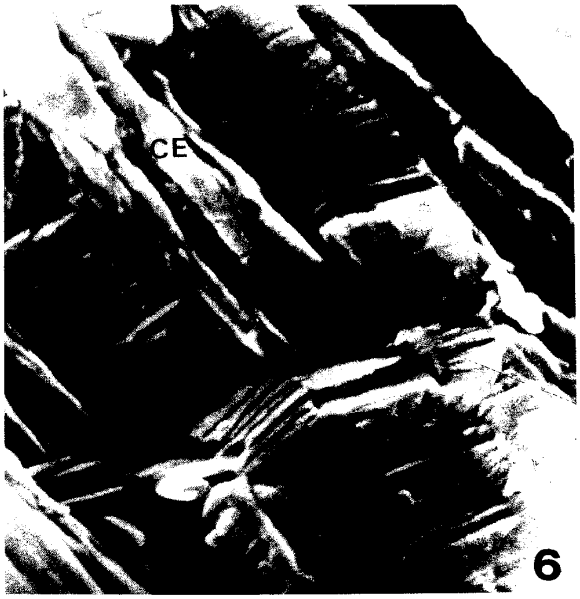
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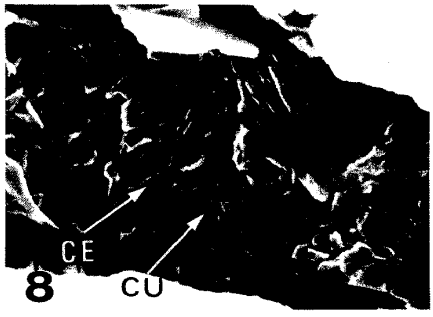
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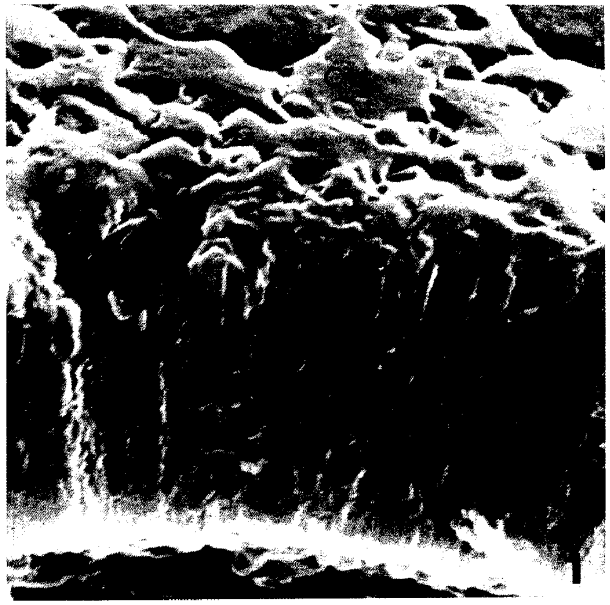

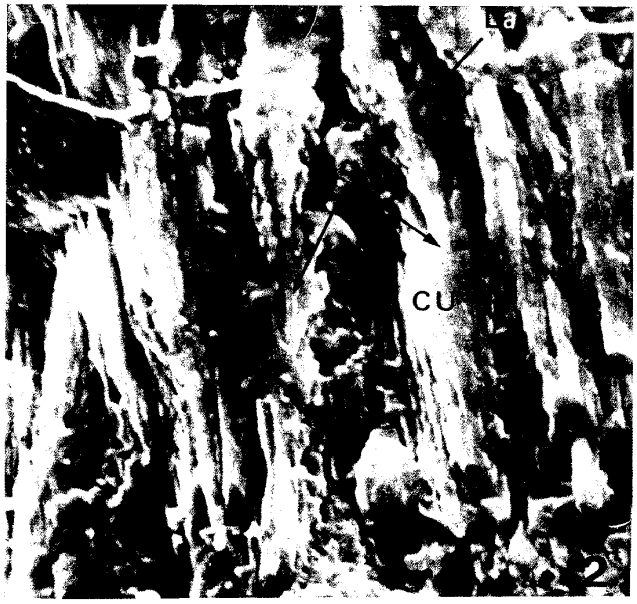
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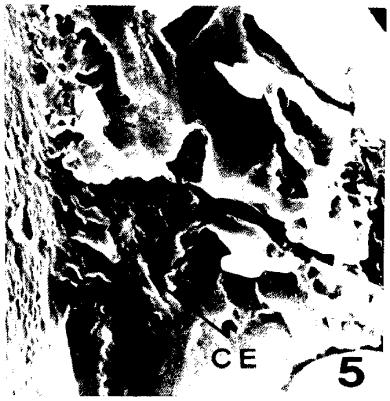
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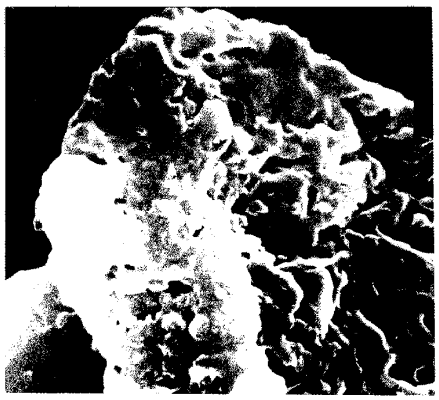


Plate 4

(All figures are scanning electron micrographs)

Fig. 1. *Islandiella norcrossi* (Cushman).
Fractured and etched cross section, showing fibrous crystalline structure of final chamber wall. Note non-branching crystal elements perpendicular to test surface (compare with bundle-shaped crystalline structure in Fig. 2). Sample NT–4, etched with Glutaraldehyde-phosphoric acid solution. ×6000.

Fig. 2. *Islandiella sublimbata* (Asano and Nakamura).
Etched and fractured cross section of penultimate chamber wall, showing bundle-shaped crystalline structure. Note that crystal units (CU) consisting of columnar crystal elements (CE) are diverging outward (upper side), new crystal units are formed onto preceding crystal units, which are bounded by secondary organic layer (La). Sample ST–3, treated with NaOCl. ×3000.

Figs. 3, 4. *Islandiella setanaensis* (Asano and Nakamura).
3. Etched and fractured cross section, showing bundle-shaped crystalline structure. Note respective microgranules in obliquely fractured section correspond to respective crystal elements. Sample ST–7, treated with NaOCl. ×6600.
4. Etched and fractured cross section, showing wavy and shrink-proof crystal elements. Sample ST–7, treated with NaOCl. ×6600.

Fig. 5. *Cassidulina carinata* Silvestri.
Polished and etched cross section of keel, showing intricate crystalline structure. Note that branching crystal elements are not so strongly intricated as compared with the structure of chamber wall, and their preferred orientations are in a direction of keel. Sample OK–20, etched with Glutaraldehyde-phosphoric acid solution. ×4000.

Fig. 6. *Islandiella japonica* (Asano and Nakamura).
Polished and etched cross section, showing the tip of primary tongue. Note strongly branching crystal elements. Sample SW–4, etched with Glutaraldehyde-phosphoric acid solution. ×5000.

Fig. 7. *Islandiella yabei* (Asano and Nakamura).
Polished and etched cross section, showing the tip of apertural ridge. Note dendritic crystal units and strongly branching crystal elements. Sample ST–4, etched with Glutaraldehyde-phosphoric acid solution. ×5000.

Plate 5

(All figures are scanning electron micrographs)

Fig. 1. *Islandiella norcrossi* (Cushman).
Etched and fractured cross section, showing fibrous crystalline structure. Different crystallographic orientation on lower side shows sutured region. Note needle-shaped crystal elements. Sample OG–20. ×7500.

Fig. 2. *Globocassidulina nojimana* (Kuwano).
Polished and etched cross section, showing intricate crystalline structure and beaded organic layer (La). Sample MU–2. ×7200.

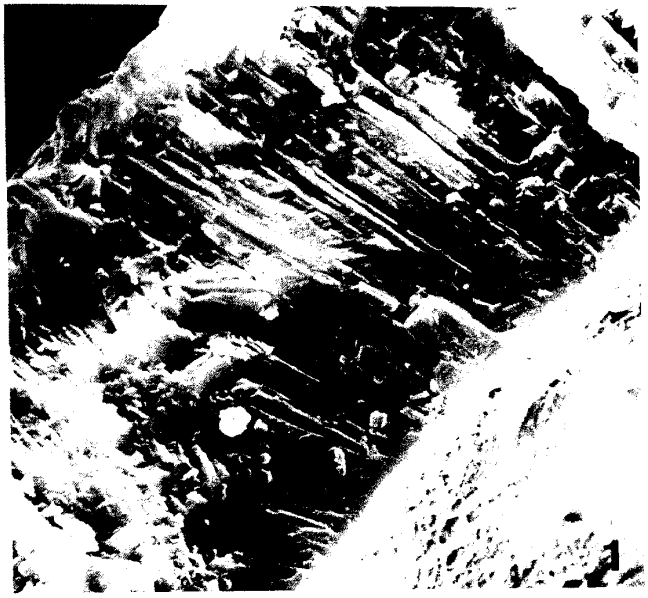
Fig. 3. *Paracassidulina miuraensis* (Higuchi).
Polished and etched cross section of septal chamber wall, showing branching crystal elements. Note that preferred orientation of crystal elements is almost parallel with test surface, and pseudolip (PL) formed in a direction of prolongation of crystal elements. Sample MU–5. ×6000.

Fig. 4. *Globocassidulina undata* (Kuwano).
Polished and etched cross section of final chamber wall, showing obliquely arranged crystal elements (CE) and the mold of pore tubule (Pt) in intricate crystalline structure. Sample MU–1. ×9300.

Fig. 5. *Paracassidulina nabetaensis* Nomura, sp. nov. .....p. 98
Polished and etched cross section showing organic pore lining (La). Sample, Recent beach sand in Nabeta cove, Izu Peninsula. ×5000.

Fig. 6. *Paracassidulina sagamiensis* (Asano and Nakamura).
Dissected specimen, showing apertural modification of final and earlier chambers. PL=pseudolip, ST=secondary tongue, AR=apertural ridge, SF=septal foramen of penultimate aperture. Sample KR–5. ×150.

Fig. 7. *Islandiella sublimbata* (Asano and Nakamura).
Younger specimen of microspheric form, showing serrated keel. Sample ST–11, ×50.

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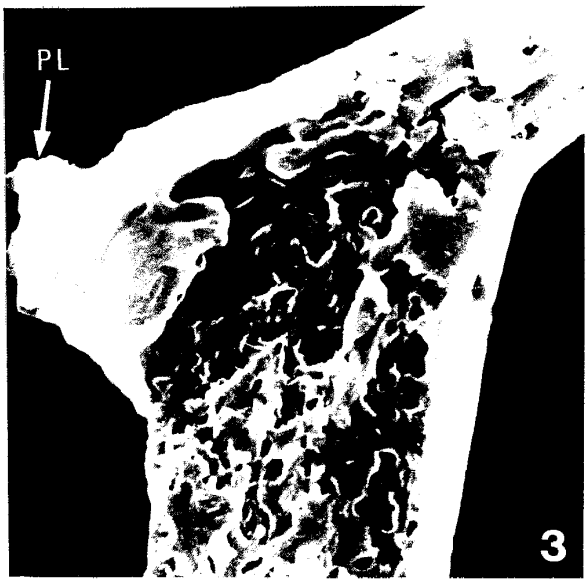
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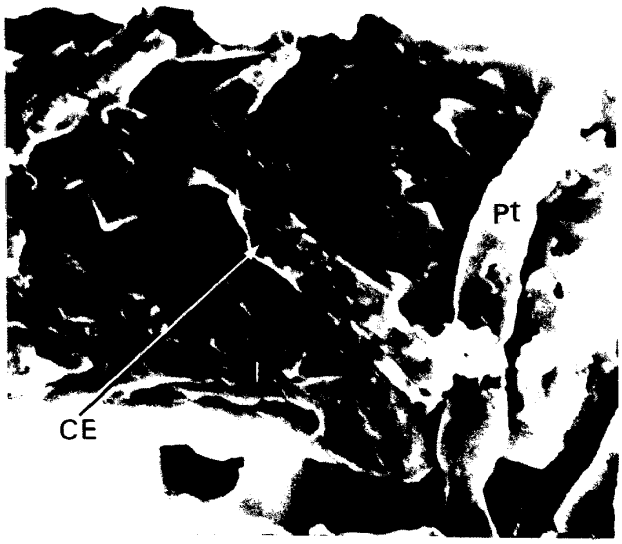
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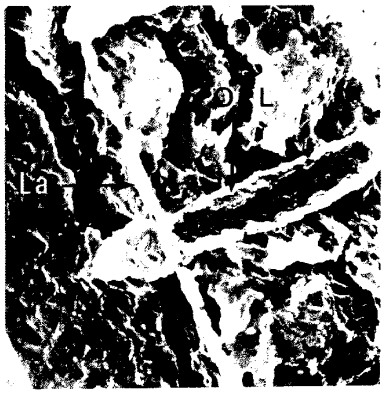
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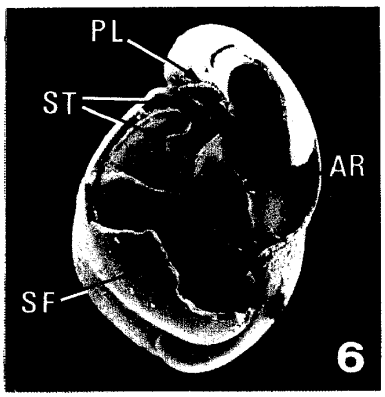
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Plate 6

(All figures are scanning electron micrographs)

Fig. 1. *Islandiella japonica* (Asano and Nakamura).
Etched and fractured cross section, showing bundle-shaped crystalline structure. Note branching crystal elements running obliquely to pore tubule (Pt). Sample SW–3, etched with Glutaraldehyde-phosphoric acid solution. ×6000.

Fig. 2. *Burseolina pacifica* (Cushman).
Etched cross section of final chamber wall, showing intricate crystalline structure. Note crystal elements (CE) arranged obliquely. CU=crystal unit, Pt=pore tubule. Sample OK–14, etched with Glutaraldehyde-phosphoric acid solution. ×9300.

Plate 7

(All figures are scanning electron micrographs)

Figs. 1–5. *Takayanagia delicata* (Cushman). ..... p. 53

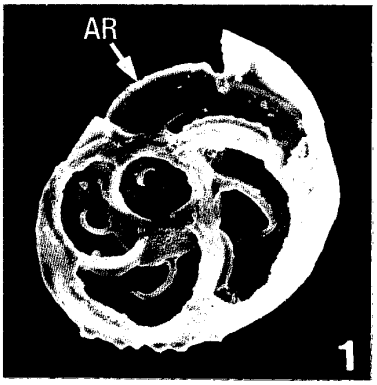
1. Embedded and opened specimen, showing horizontal view. AR=apertural ridge. Sample BS–16. ×400.
2. Embedded and opened specimen, showing vertical view. Sample BS–16. ×200.
3. Oblique profile view of Fig. 1, showing apertural ridge (AR) and previous apertures. SF=septal foramen. ×300.
4. Detail of Fig. 2, showing proloculus aperture (PA). ×680.
5. Surface microtopography, showing outer veneer consisting of microgranular crystallites, and slightly depressed pore margin. Sample BS–16. ×5000.

Figs. 6–10. *Cassidulinoides subcylindricus* Nomura, sp. nov. ..... p. 51

6. Embedded and opened specimen, showing horizontal view. Sample AR–6. ×200.
7. Detail of aperture. Note simple aperture. Cristate tooth (CT) closely resembles lip (L), which encircles apertural foramen. Sample AR–6. ×450.
8. Detail of final aperture indicated in Fig. 6. Note simple modification. Primary tongue and cavity not formed. CP=copula, Lg=ledge. ×500.
9. Slightly etched surface microtopography, showing irregular boundaries of crystal units of outer veneer. Sample AR–6, etched with Glutaraldehyde-phosphoric acid solution. ×3000.
10. Etched surface microtopography, showing granular crystal units and shape of pores. Note outer veneer completely dissolved. Sample AR–6. ×1500.

Figs. 11, 12. *Islandiella helenae* (Feyling-Hanssen and Buzas).

11. Detail of penultimate aperture, showing lip (L), cristate tooth (CT), apertural ridge (AR), sulcus (S), and secondary tongue (ST). Sample OG–20. ×400.
12. Etched surface microtopography, showing crystal units of outer veneer separated by interlocking irregular surface. Note that outermost microgranular crystallites are dissolved. Sample OG–20. ×5000.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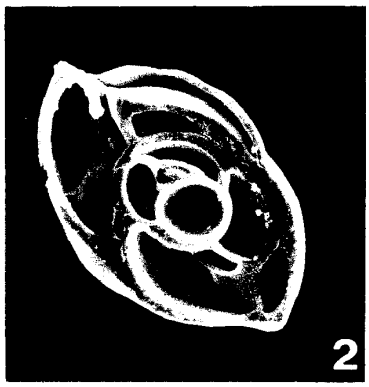
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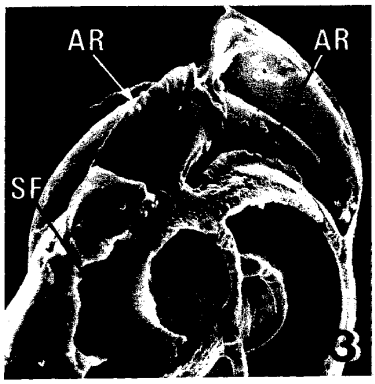
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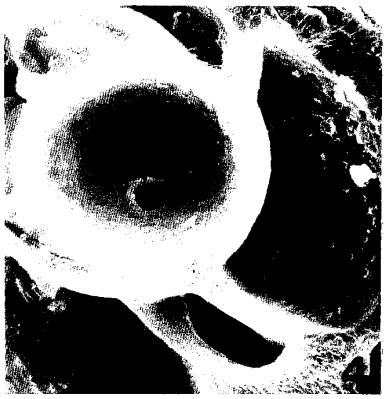
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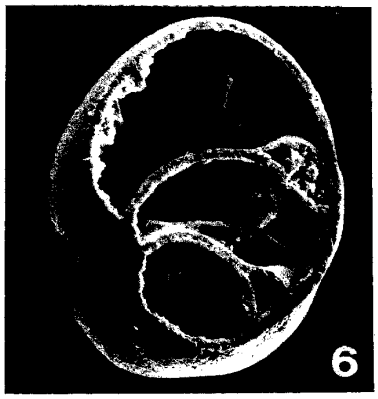
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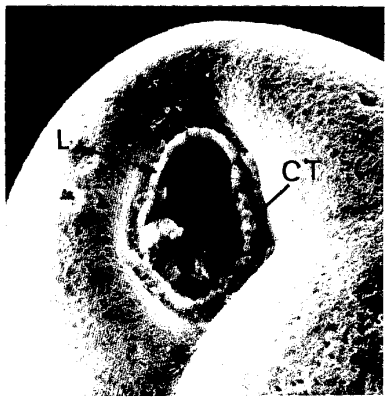
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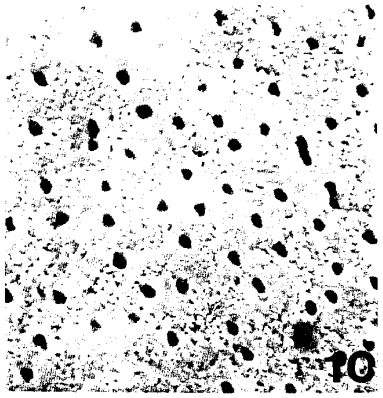
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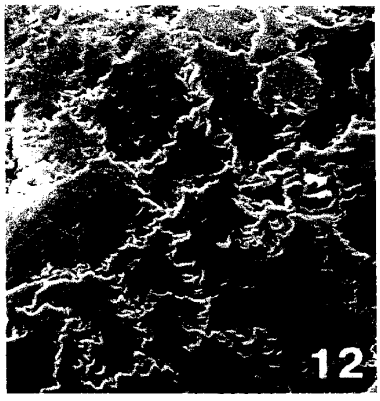
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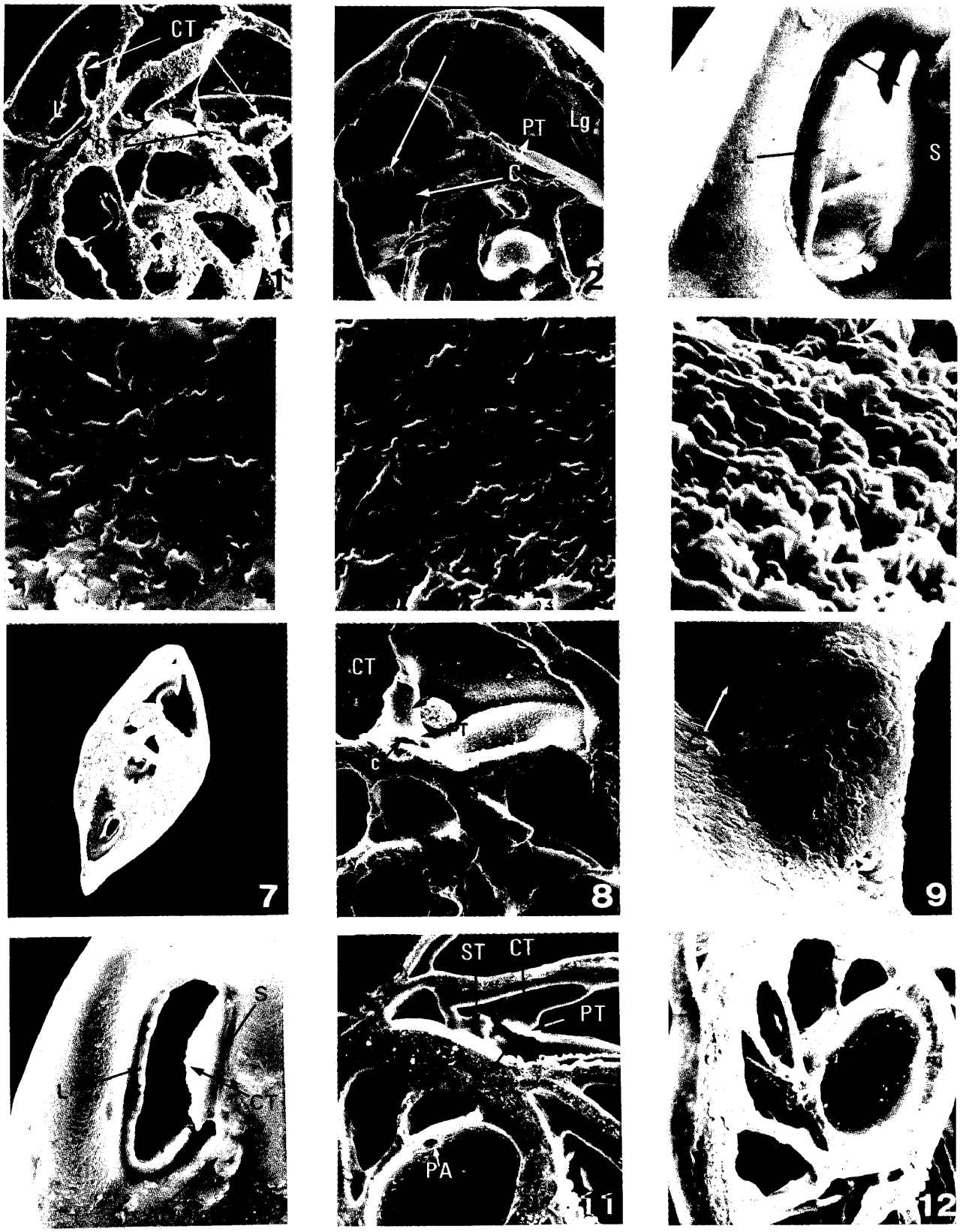
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Plate 8

(All figures are scanning electron micrographs)

Figs. 1, 2. *Islandiella helenae* (Feyling-Hanssen and Buzas).

1. Detail of embedded and opened specimen, showing ontogenetic development of aperture. Sample OG–20. ×300.

2. Detail of embedded and opened specimen, showing apertural modification of final, penultimate, and antipenultimate chambers. PT=primary tongue, C=cavity, CT=cristate tooth, Lg=ledge. Sample OMM–9. ×220.

Figs. 3–10. *Islandiella norcrossi* (Cushman).

3. Detail of final aperture, showing lip (L), cristate tooth (CT), sulcus (S), and secondary tongue (ST). Sample AR–7. ×900.

4. Etched surface microtopography, showing crystal units of outer veneer. Note that pores are placed on boundaries between crystal units. Sample AR–7. ×5000.

5. Etched surface microtopography, showing irregularly interlocking crystal units of outer veneer. Degree of etching is more progressed in comparison with Fig. 4. Sample AR–7. ×5000.

6. Etched surface microtopography, showing crystal elements. Note truncated crystal elements indicative of rhombohedral cleavage. Outer veneer completely dissolved. Sample AR–7. ×5000.

7. Embedded and opened specimen, showing vertical view. Sample OG–7. ×120.

8. Detail of embedded and opened specimen, showing toothplate of penultimate aperture. CP=copula, PT=primary tongue, C=cavity, CT=cristate tooth. Sample BS–5. ×290.

9. Detail of primary tongue, showing columnar appearance devoid of internal free folding part. Note sutured veneer. C=cavity. Sample AR–6. ×3800.

10. Detail of aperture, showing lip (L), cristiate tooth (CT), sulcus (S), apertural ridge (AR), and secondary tongue (ST). Secondary tongue and cristate tooth not fused with each other (compare with Fig. 3). Sample AR–9. ×600.

Figs. 11, 12. *Islandiella wakasaensis* (Asano and Nakamura).

11. Detail of antipenultimate aperture, showing internal modification. PT=primary tongue, ST=secondary tongue, C=cavity, CP=copula, CT=cristate tooth. Sample, Recent sediments off Rumoi, Hokkaido. ×230.

12. Detail of previous whorl showing apertural ontogenetic development. The same sample as the above. ×230.

Plate 9

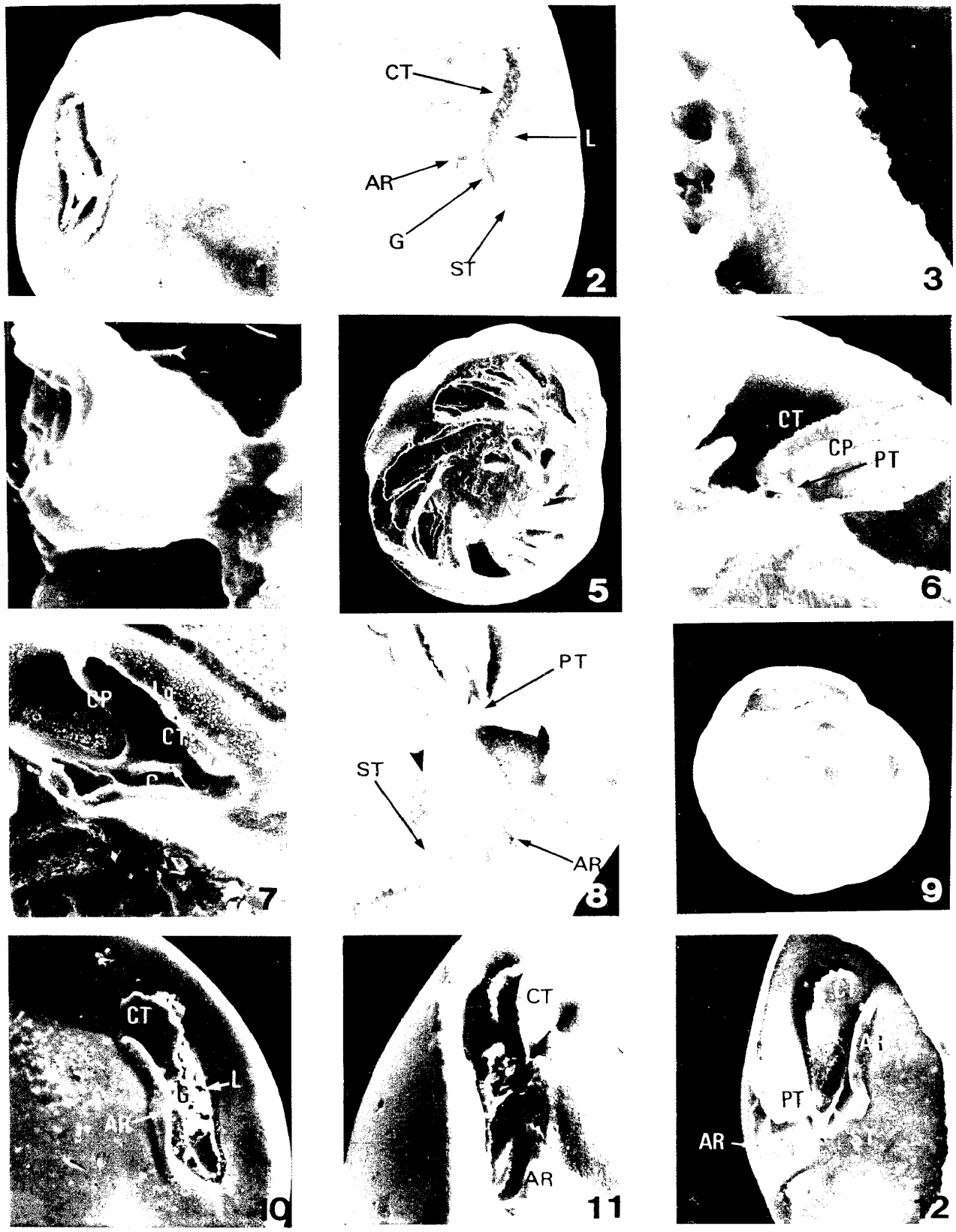
(All figures are scanning electron micrographs)

Figs. 1–8. *Islandiella sublimbata* (Asano and Nakamura).

1. Detail of final aperture. Sample ST–3. ×150.
2. Detail of final aperture, showing cristate tooth (CT), secondary tongue (ST), spertural ridge (AR), gap (G), and lip (L). Sample ST–3. ×500.
3. Detail of Fig. 2, showing serrated cristate tooth. ×2000.
4. Detail of Fig. 3, showing pustules. Note rudimentary pustules in basal part. ×5000.
5. Embedded and opened specimen, showing horizontal view. Sample ST–3. ×60.
6. Detail of antipenultimate and earlier apertures. Note cristate tooth (CT), primary tongue (PT), and cavity (C). Sample ST–3. ×250.
7. Detail of internal modification of penultimate aperture. CT=cristate tooth, CP=copula, PT=primary tongue, C=cavity, Lg=ledge. Sample ST–3. ×300.
8. Detail of internal modification of final aperture. Based on abnormal specimen. ST=secondary tongue, PT=primary tongue, AR=apertural ridge. Sample ST–3. ×180.

Figs. 9–12. *Islandiella yabei* (Asano and Nakamura).

9. Embedded and opened specimen. Note primary tongue. Sample ST–6. ×100.
10. Detail of final aperture, showing cristate tooth (CT), secondary tongue (ST), apertural ridge (AR), and lip (L). Gap (G) formed between cristate tooth and secondary tongue. Sample ST–3. ×150.
11. Detail of final aperture, showing abnormal type. Note double-cristate tooth (CT). AR=apertural ridge. Sample ST–3. ×150.
12. Detail of internal modification of final aperture and penultimate aperture. Note the position of primary tongue (PT). ST=secondary tongue, CT=cristate tooth, AR=apertural ridge. Sample ST–3. ×150.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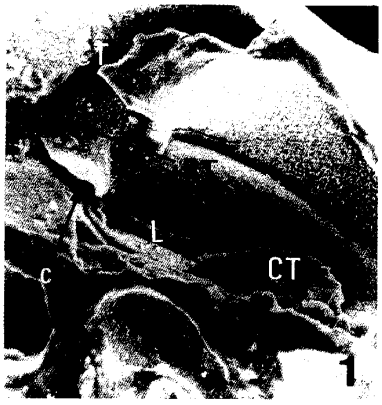
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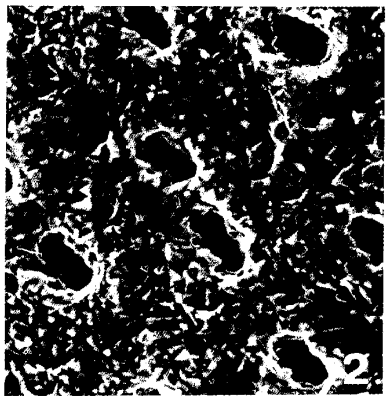
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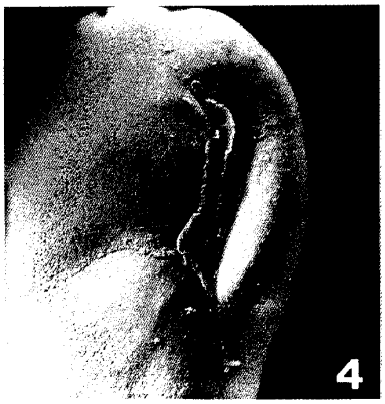
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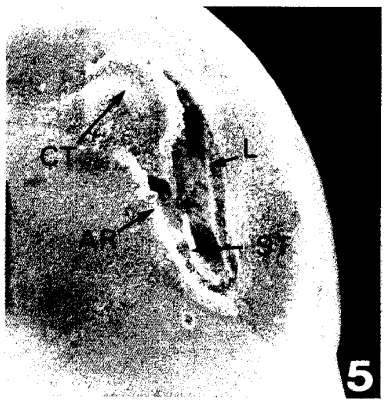
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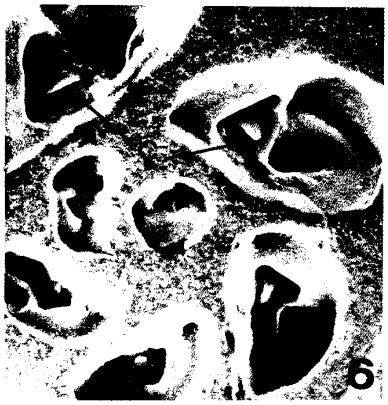
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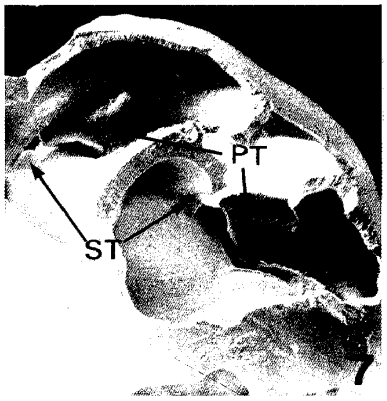
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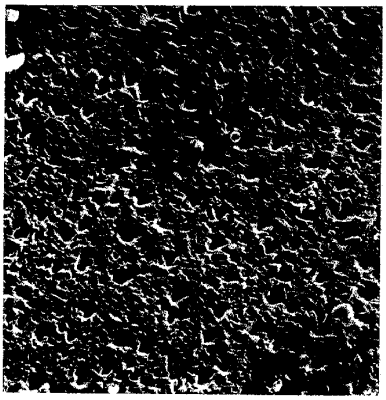

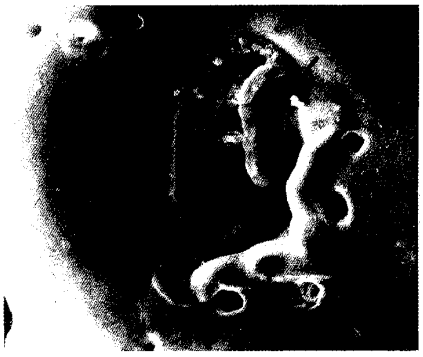

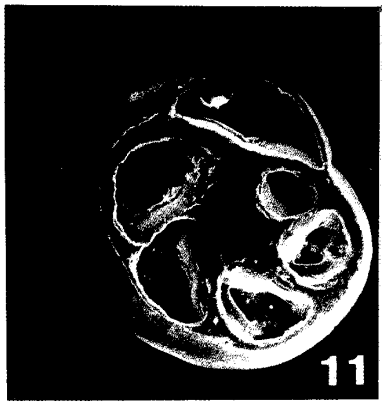
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Plate 10

(All figures are scanning electron micrographs)

Figs. 1–3. *Islandiella yabei* (Asano and Nakamura).

1. Detail of internal modification of penultimate aperture. Toothpate formed in anterior corner of preceding apertural face. CT=cristate tooth, PT=primary tongue, C=cavity, L=lip. Sample ST–3. ×150.

2. Etched surface microtopography, showing granular crystal elements and oval pores on outer test surface. Outer veneer completely dissolved. Sample ST–3, etched with Glutaraldehyde-phosphoric acid solution. ×5000.

3. Etched surface microstructure, showing pointed crystal units and rounded pores of inner test surface. Note that pores are surrounded with crystal elements and irregular sutures (arrow). Inner veneer completely dissolved. Sample ST–3, etched with Glutaraldehyde-phosphoric acid solution. ×5000.

Figs. 4–10. *Islandiella japonica* (Asano and Nakamura).

4. Detail of final aperture (compare with Fig. 5). Sample SW–3. ×130.

5. Detail of final aperture (compare with Fig. 4). CT=cristate tooth, AR=apertural ridge, L=lip, ST=secondary tongue. Sample SW–3. ×130.

6. Detail of horizontally opened specimen, showing inner whorl. Note developmental mode of primary tongue. C=cavity. Sample SW–4. ×150.

7. Detail of dissected specimen, showing internal modification of final and penultimate apertures. Note primary tongue (PT) formed on preceding apertural face and secondary tongue (ST) formed on previous whorl. Sample SW–4. ×50.

8. Detail of aperture of neanic stage. In this stage, primary tongue appears a cristate tooth (CT). Rounded openings are boring. AR=apertural ridge. Sample SW–3. ×250.

9. Embedded and opened specimen. Sample SW–4. ×50.

10. Etched surface structure, showing granular crystal elements and numerous rounded pores. Outer veneer completely dissolved. Sample SW–4, etched with Glutaraldehyde-phosphoric acid solution. ×1500.

Fig. 11. *Islandiella setanaensis* (Asano and Nakamura).

Embedded and opened specimen, showing horizontal view. Sample ST–1. ×80.

Plate 11

(All figures are scanning electron micrographs)

Figs. 1–3. *Islandiella setanaensis* (Asano and Nakamura).

1. Dissected specimen, showing internal modification of final and penultimate apertures. Note primary tongue (PT), secondary tongue (ST), and apertural ridge (AR). Sample ST–1. ×150.

2. Dissected specimen, showing internal modification of final aperture and penultimate aperture. Note primary tongue (PT), and apertural ridge (AR). Tip of primary tongue is partly destroyed. Sample ST–1. ×150.

3. Detail of embedded and opened specimen, showing internal modification of final and anti-penultimate apertures. PT=primary tongue, ST=secondary tongue. Sample ST–1. ×140.

Figs. 4–9. *Islandiella islandica* (Nørvang). .....p. 47

4. Apertural view. Sample OG–20. ×100.

5. Detail of final aperture, showing cristate tooth (CT), secondary tongue (ST), apertural ridge (AR), and nodose lip (L). Sample OG–10. ×400.

6. Embedded and opened specimen, showing developmental mode of internal modification. Sample OG–10. ×150.

7. Detail of proloculus aperture (PA). Note simple rounded aperture without modification. Sample OG–10. ×600.

8. Surface microtopography in earlier portion of test. Note rugged veneer and slit-shaped pores (compare with Fig. 9). Sample OG–10. ×1500.

9. Surface microtopography of penultimate chamber, showing smooth veneer, and rounded and triangular pores (compare with Fig. 8). Sample OG–10. ×1500.

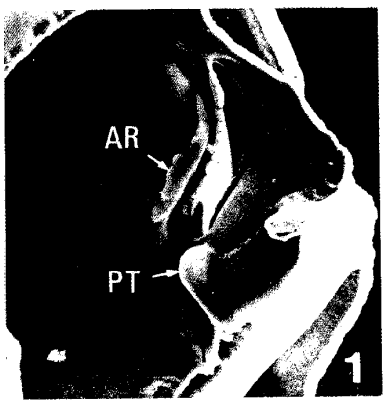
Figs. 10, 11. *Islandiella kazusaensis* (Asano and Nakamura).

10. Embedded and opened specimen. Note developmental mode of primary tongue. Sample BS–4. ×90.

11. Detail of final aperture, showing protruding cristate tooth (CT) and apertural ridge (AR). Sample BS–4. ×230.

Fig. 12. *Globocassidulina moluccensis* (Germeraad).

Detail of final aperture, showing lip (L) and cristate tooth (CT). Sample OK–18. ×400.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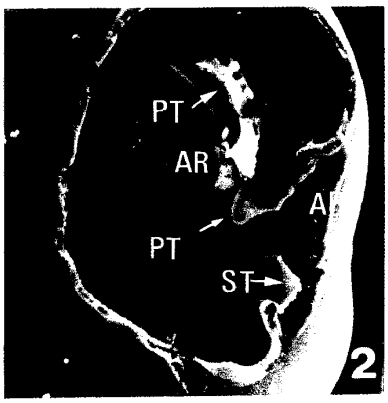
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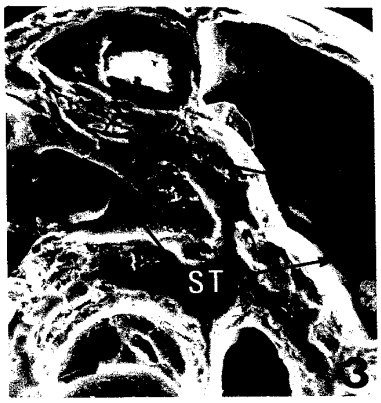
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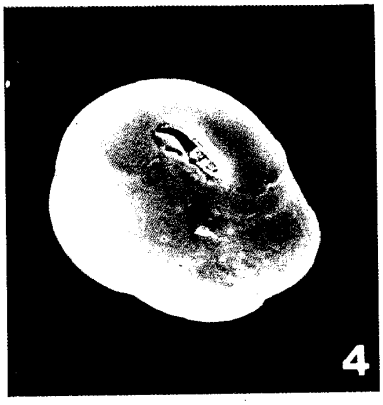
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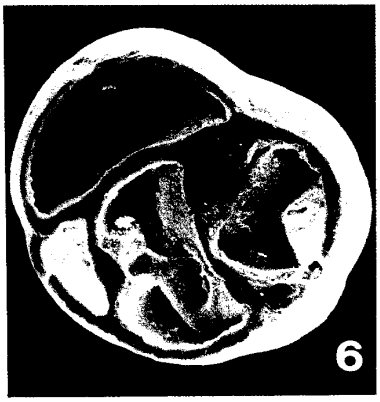
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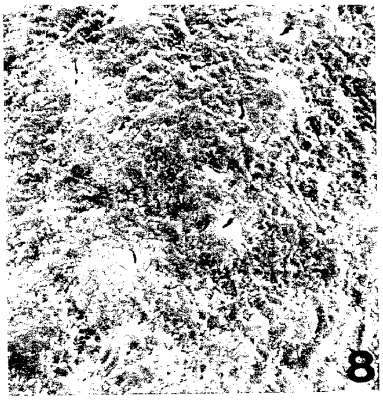
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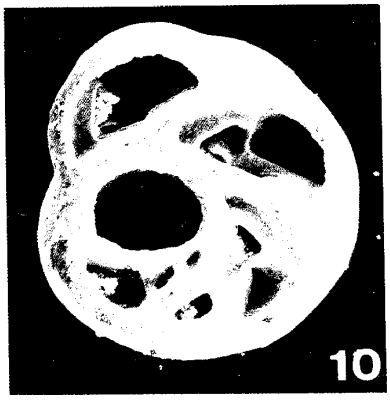
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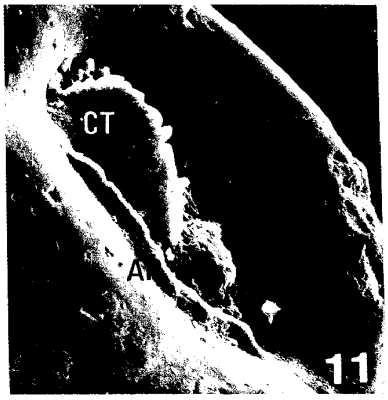
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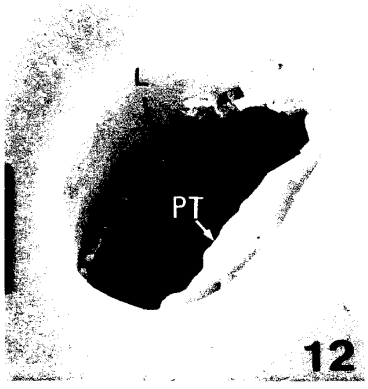
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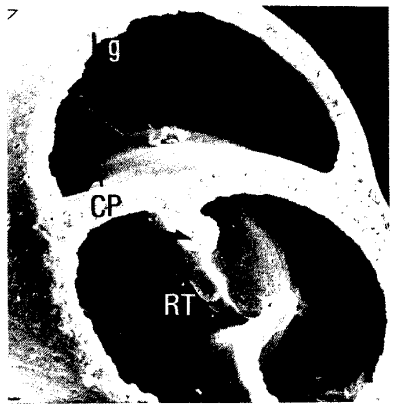
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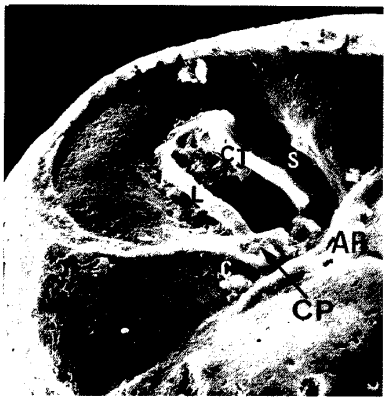
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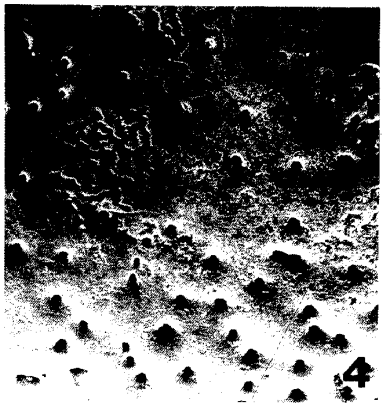
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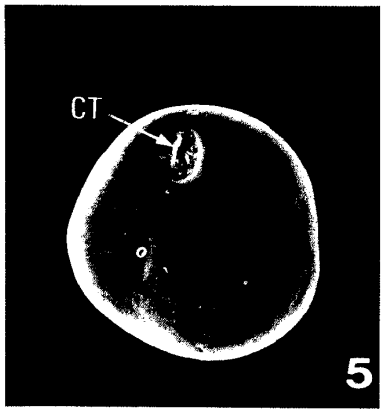
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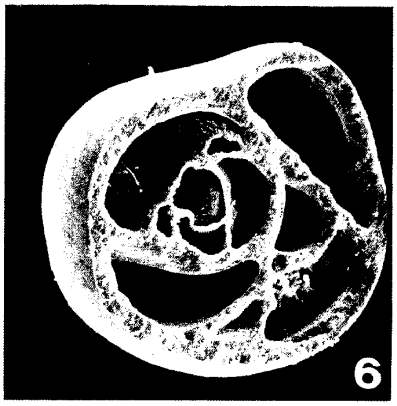
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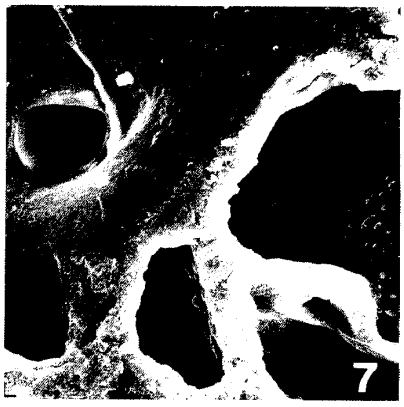
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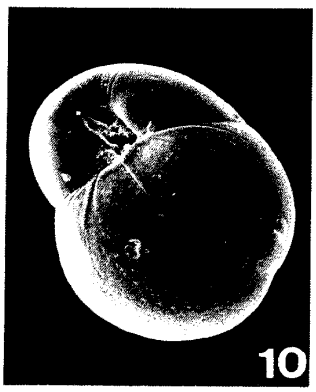
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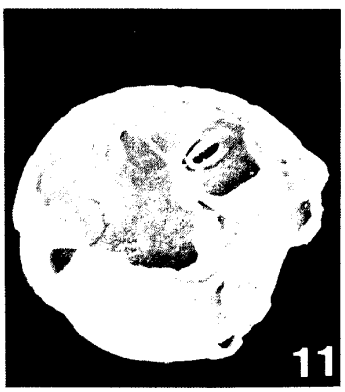
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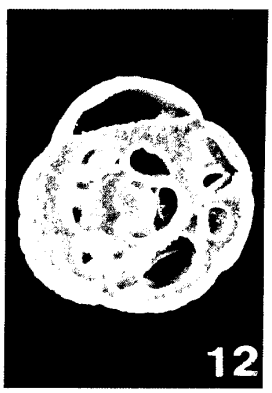
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13

Plate 12

(All figures are scanning electron micrographs)

Figs. 1, 2. *Globocassidulina moluccensis* (Germeraad).

1. Detail of opened specimen, showing primary tongue (PT) of penultimate aperture and obliquely viewed final aperture. CP=copula, Lg=ledge. Sample OK–18. ×200.

2. Surface microtopography on earlier portion, showing microgranular veneer and slit-shaped pores. Note parallel pores. Sample OK–18. ×1500.

Figs. 3, 4. *Globocassidulina pseudoquadrata* Nomura, sp. nov. ..... p. 62

3. Detail of penultimate aperture, showing lip (L), cristate tooth (CT), sulcus (S), and apertural ridge (AR). Note copula of final aperture adhering to proximal end of aperture. C= cavity, CP=copula. Sample OK–21. ×350.

4. Surface microtopography on earlier portion, showing slightly depressed rounded pores. Vermiculated patterns may be resulted from some etching effects. Sample OK–21. ×500.

Figs. 5–8. *Globocassidulina parviapertura* Nomura, sp. nov. ..... p. 56

5. Apertural view. Note slightly protruding cristate tooth (CT). Sample OK–18. ×70.

6. Embedded and opened specimen, showing internal structure. Sample OK–18. ×120.

7 Detail of Fig. 6, showing previous apertures. ×500.

8. Surface microtopography on earlier portion, showing outer veneer and slit-shaped pores. Sample OK–18. ×5000.

Figs. 9, 10. *Globocassidulina gemma* (Todd).

9. Surface microtopography on earlier portion, showing oval pores tending to slit-shaped. Note downward pointing narrow grooves accompanied with slit-shaped pores. Sample OK–14. ×1500.

10. Apertural view of whole specimen in neanic stage. Note grooves running out of aperture. Sample OK–14. ×150.

Figs. 11, 12. *Globocassidulina undata* (Kuwano).

11. Profile view of specimen with broken final chamber, showing undulated chamber attachment and aperture. Sample BS–5. ×150.

12. Embedded and opened specimen, showing internal structure. Sample BS–6, ×150.

Fig. 13. *Globocassidulina matobai* Nomura, sp. nov. ..... p. 65

Embedded and opened specimen, showing oblique view. Note developmental mode of aperture. Sample BS–2. ×140.

Plate 13

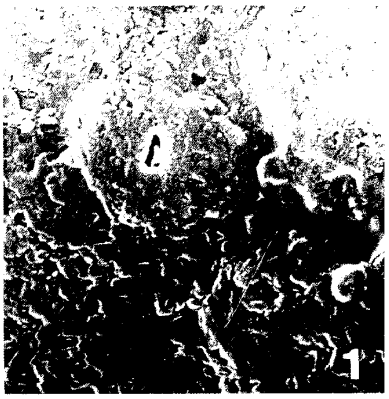
(All figures are scanning electron micrographs)

Fig. 1. *Globocassidulina undata* (Kuwano).
Surface microtopography of earlier portion, showing papillae accompanied with slit-shaped pores in center. Note rugged outer veneer. Sample MU–1. ×5000.

Figs. 2–4. *Globocassidulina mucronata* Nomura, sp. nov. .....p. 63
2. Surface microtopography of penultimate chamber, showing irregular crystal units of outer veneer. Sample OK–19. ×1500.
3. Surface microtopography of earlier portion, showing papillae (compare with Fig. 2). Sample OK–19. ×500.
4. Surface microtopography of middle portion, showing papillae and rudimentary papillae (compare with Figs. 2, 3). Sample OK–19. ×3000.

Figs. 5, 6. *Globocassidulina subglobosa* (Brady).
5. Dissected specimen showing internal modification of final aperture and preceding aperture. Note the position of toothplate showing primary tongue (PT) and numerous striations running out of aperture. L=lip, C=cavity. Sample OK–21. ×150.
6. Surface microtopography of earlier portion, showing slit-shape pores. Elongate axis of pores runs against aperture. Sample OK–21. ×1500.

Figs. 7–12. *Globocassidulina gemma* (Todd).
7. Apertural view of specimen with apertural grooves (AG) and other apertural modification. S=sulcus, L=lip. Sample OK–21. ×100.
8. Detail of aperture, showing cristate tooth (CT), sulcus (S), and protruding lip (L). Sample OK–21. ×200.
9. Internal view of proloculus, showing aperture (PA) and radiating grooves. Sample OK–21. ×240.
10. Internal view of penultimate chamber, showing numerous pores and non-perforated antipenultimate septal chamber wall. Sample OK–21. ×300.
11. Internal view of earlier chamber, showing rounded pores. Note differences of pore diameter. Depressed and larger pores near sutural region (lower side). Sample OK–21. ×1000.
12. Surface microtopography of earlier portion, showing slit-shaped pores arranged in parallel. Sample OK–21. ×400.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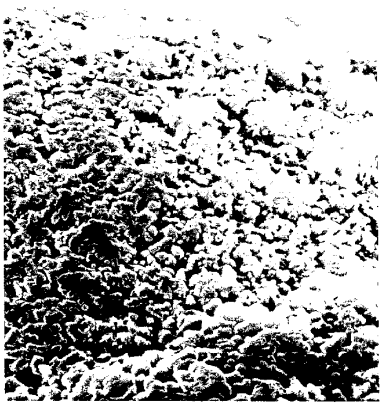


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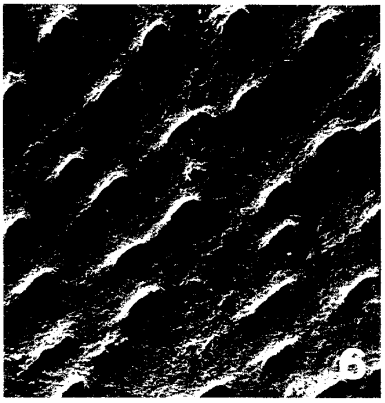
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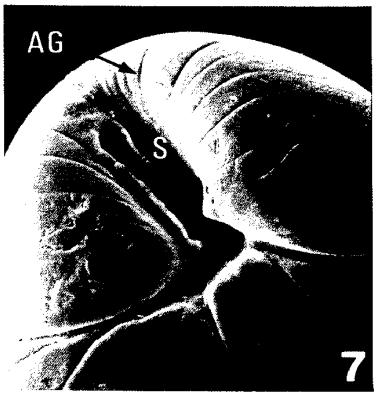
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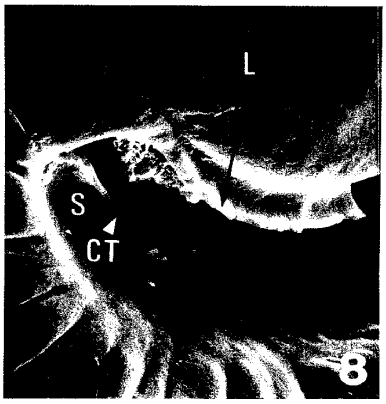
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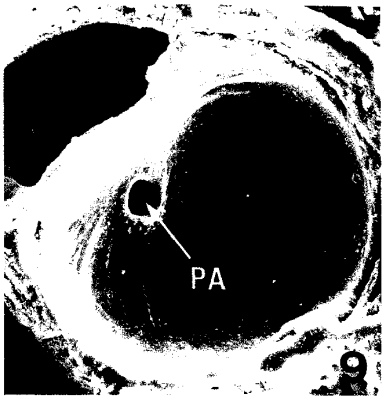
PA
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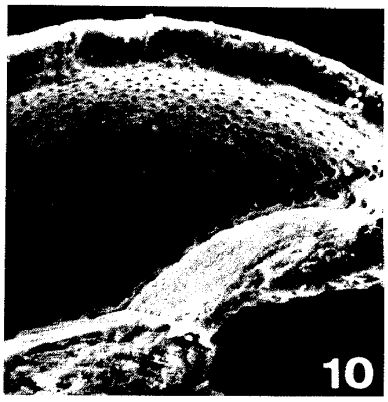
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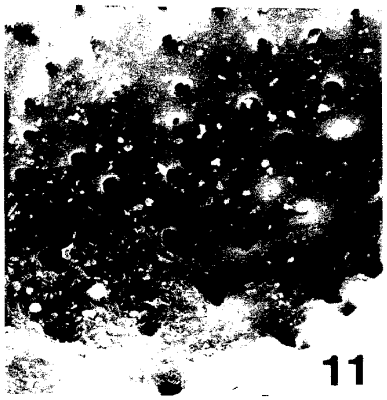
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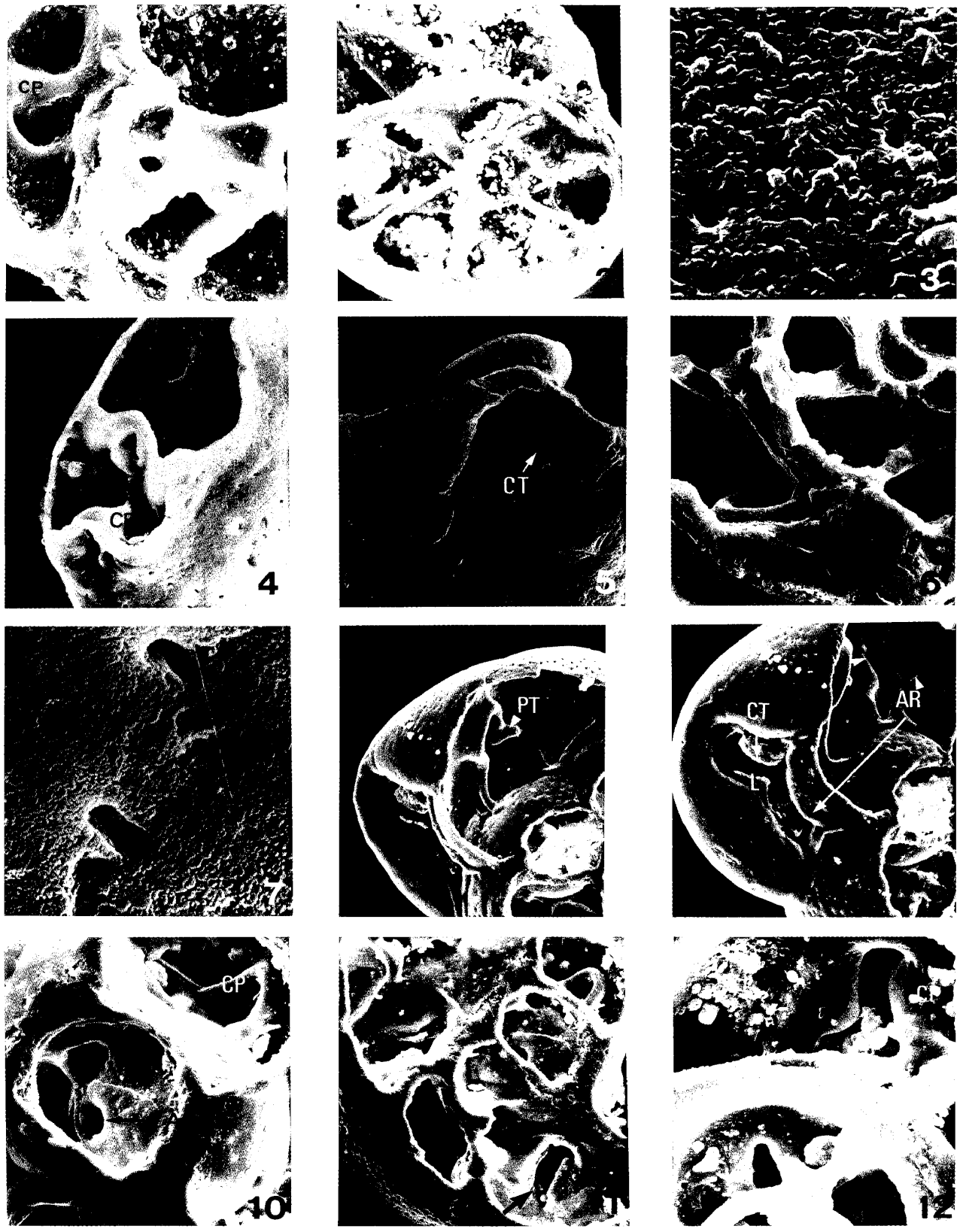
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Plate 14

(All figures are scanning electron micrographs)

Figs. 1–3. *Globocassidulina crepidula* (Kuwano).

1. Embedded and opened specimen, showing internal modification of previous aperture. Note copula (CP) without internal free part. Sample BS–2. ×500.

2. Embedded and opened specimen, showing inner structure of previous chambers. Sample BS–2. ×300.

3. Surface microtopography, showing microgranular crystallites of outer veneer and rounded pores. Sample BS–2. ×5000.

Figs. 4–7. *Globocassidulina venustas* Nomura, sp. nov. .....p. 60

4. Dissected specimen, showing final, penultimate, and antipenultimate apertures. Note biserial arrangement of copula (CP) without internal free part. Sample BS–7 (A). ×500.

5. Detail of Fig. 4, showing ledge (Lg) and very small cristate tooth (CT). ×1500.

6. Detail of embedded and opened specimen, showing previous whorl. Note simple internal modification of respective apertures. Sample MU–1, ×800.

7. Surface microtopography, showing microgranular crystallites of outer veneer and gourd-shaped pores in elongate depressions. Sample BS–7 (A). ×5000.

Figs. 8–12. *Globocassidulina bisecta* Nomura, sp. nov. .....p. 73

8. Embedded and opened specimen, showing detail of internal modification of penultimate aperture. Note primary tongue (PT) adhering to septal chamber wall. Sample BS–9. ×180.

9. Detail of Fig. 8. Oblique view of final and antipenultimate apertures, showing tripartite feature. Note cristate tooth (CT), lip (L), and apertural ridge (AR). Secondary tongue (ST) is not formed in this species. ×200.

10. Detail of embedded and opened specimen, showing inner whorl. Note rounded embryonic aperture (PA) and successive aperture with copula (CP). Sample BS–10. ×400.

11. Detail of embedded and opened specimen, showing elongate aperture without tripartite feature in neanic stage (arrow). Compare with Figs. 8 and 9.
Sample BS–10. ×250.

12. Detail of nepionic and early ephebic apertures. CP=copula. Sample BS–9. ×400.

Plate 15

(All figures are scanning electron micrographs)

Figs. 1–5. *Globocassidulina bisecta* Nomura, sp. nov. ..... p. 73

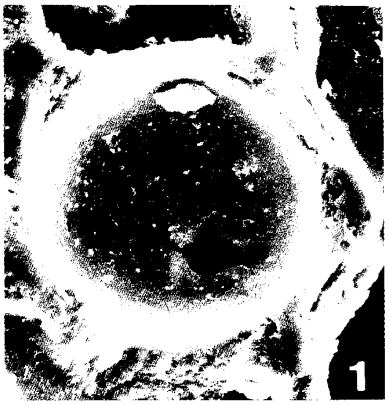
1. Internal view of proloculus aperture (PA). Note rounded aperture. Sample BS–10. ×450.
2. Internal view of nepionic aperture (NA) with copula (CP). Sample BS–10. ×500.
3. Inner test surface of antipenultimate chamber, showing rounded pores and pore rims indicated by concentric grooves. Sample BS–10. ×1500.
4. Surface microtopography on antipenultimate chamber, showing rounded pores and slightly etched outer veneer. Sample BS–10. ×500.
5. Surface microtopography on earlier portion, showing slightly depressed pore margin. Note conjugate pores. Sample BS–10. ×1500.

Figs. 6–10. *Globocassidulina parva* (Asano and Nakamura).

6. Embedded and opened specimen, showing tangential view. Sample MU–4. ×100.
7. Detail of penultimate aperture, showing cristate tooth (CT), sulcus (S), and lip (L). Copula (CP) and primary tongue (PT) are formed on penultimate apertural face. Sample MU–1. ×250.
8. Embedded and opened specimen, showing internal modification of earlier apertures. L=lip, C=cavity, CP=copula, PT=primary tongue. Sample MU–1. ×300.
9. Internal view of junction between septal wall (left side) and chamber wall (right side), showing large rounded pores arranged in a row. Sample MU–1. ×1000.
10. Surface structure, showing rounded pores and sutural grooves. Sample BS–7 (A). ×250.

Figs. 11, 12. *Globocassidulina depressa* (Asano and Nakamura).

11. Tangential view, showing tripartite aperture. Sample BS–17. ×130.
12. Detail of internal modification of final and antipenultimate apertures, showing copula (CP), primary tongue (PT), cavity (C), and cristate tooth (CT). ST=secondary tongue. Sample BS–17. ×230.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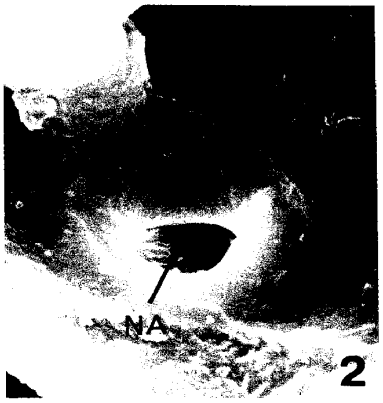
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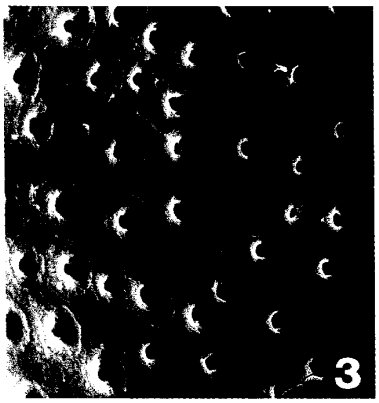
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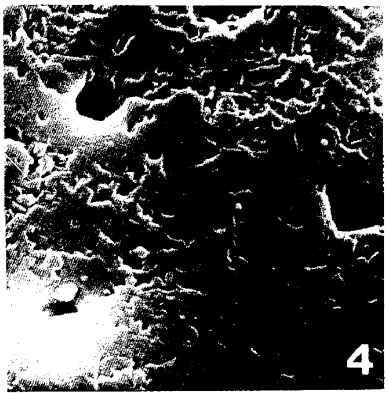
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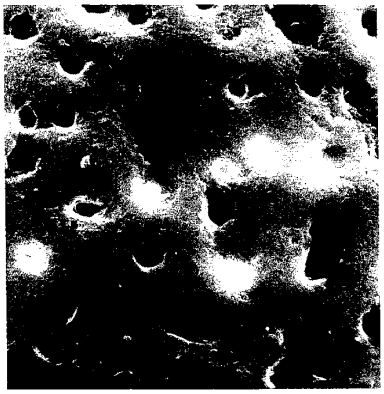

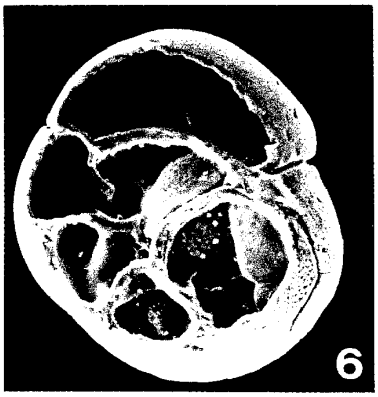
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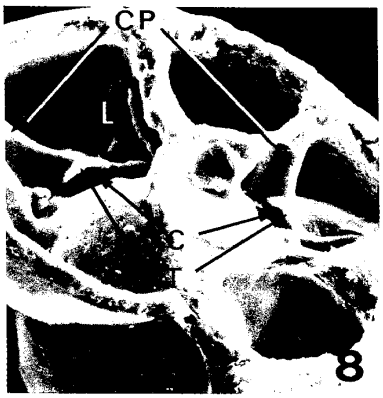
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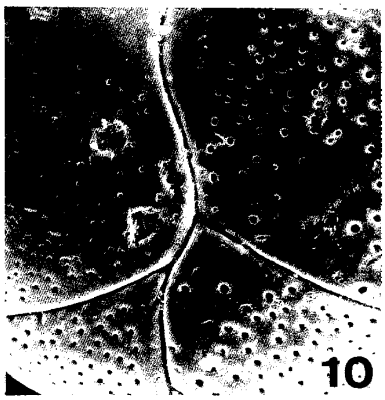
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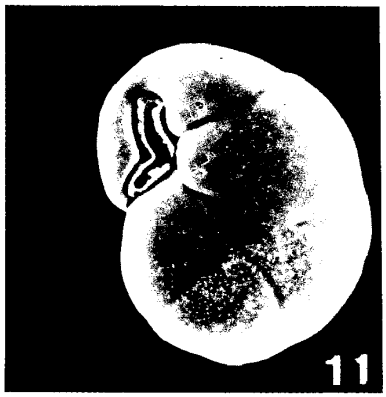
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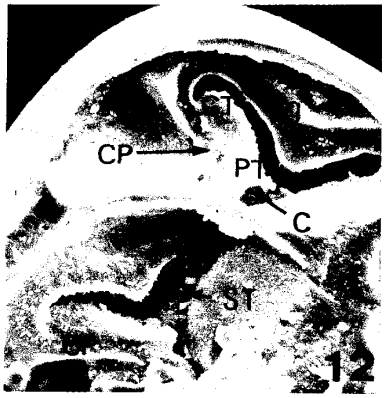
CP
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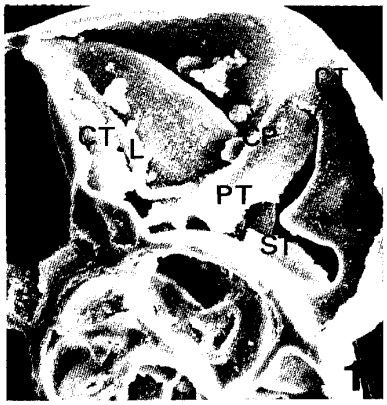
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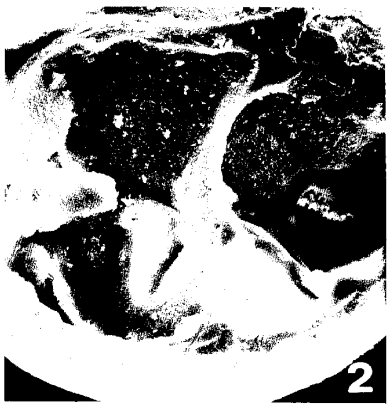
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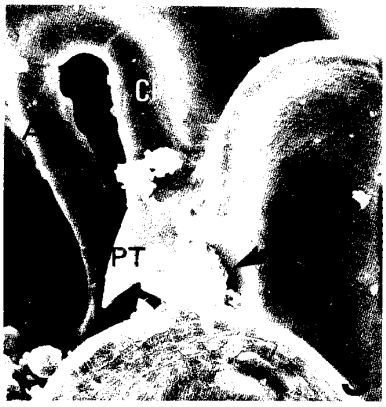
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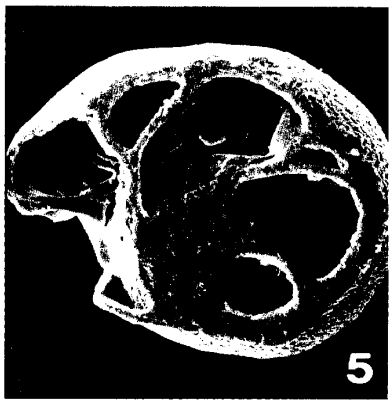
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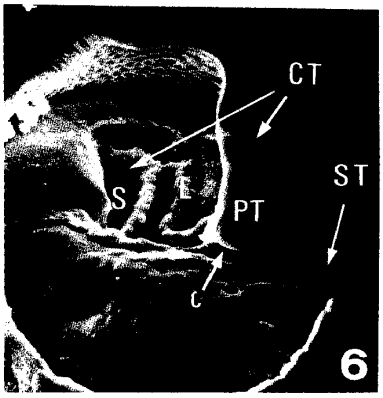
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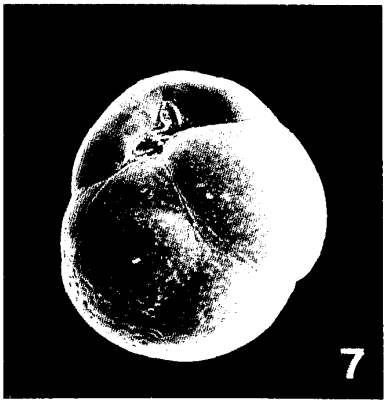
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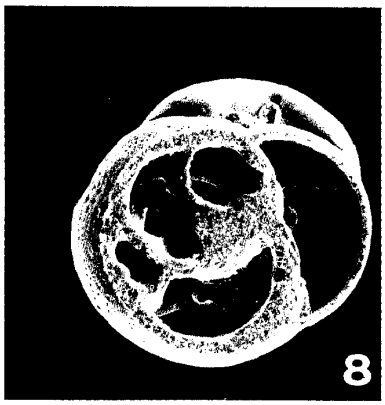
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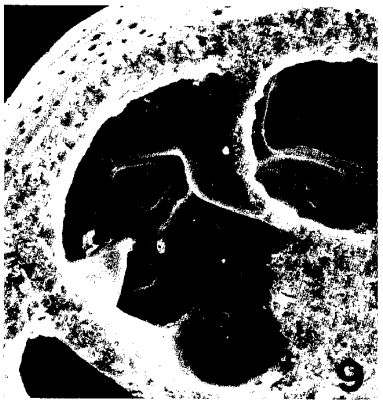
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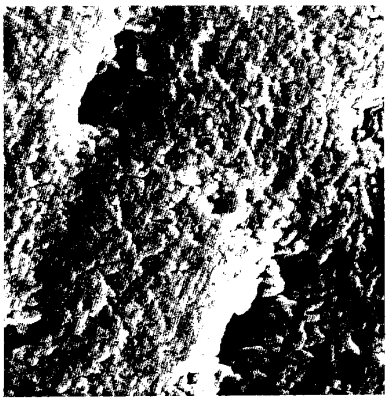

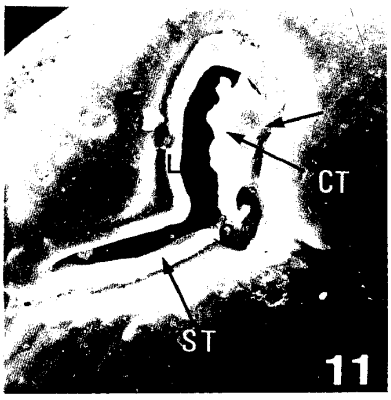
L
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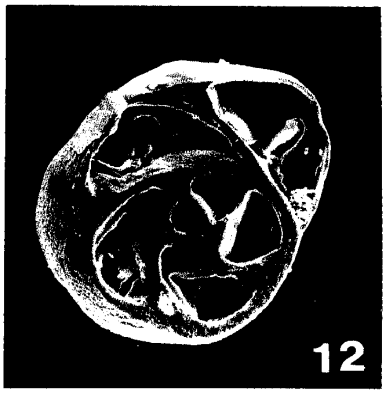
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Plate 16

(All figures are scanning electron micrographs)

Figs. 1–4. *Globocassidulina depressa* (Asano and Nakamura).

1. Internal view of final and penultimate apertures, showing copula (CP), primary tongue (PT), secondary tongue (ST), lip (L), and cristate tooth (CT). Note primary tongue adhering to preceding branch. Sample BS–17. ×250.
2. Internal view of opened specimen, showing previous aperture. Sample BS–17. ×300.
3. Detail of internal structure, showing relation between final aperture and basal branch of penultimate aperture (arrow). Note basal branch covered with primary tongue (PT). CP= copula. Sample MU–5. ×450.
4. Surface microtopography, showing crystallites of outer veneer and pores. Sample MU–5. ×5000.

Figs. 5, 6. *Globocassidulina rugosa* Nomura, sp. nov. .....p. 129

5. Embedded and opened specimen, showing horizontal view. Sample BS–7 (B). ×140.
6. Detail of aperture with broken final chamber, showing cristate tooth (CT), sulcus (S), cavity (C), lip (L), and secondary tongue (ST). Note that Primary tongue of final aperture adheres to anterior corner of preceding basal apertural branch. Sample BS–7 (B). ×300.

Figs. 7–10. *Globocassidulina subbisecta* Nomura, sp. nov. .....p. 68

7. Tangential view. Sample OK–14. ×75.
8. Embedded and opened specimen in tangential view. Note copula and primary tongue. Sample OK–14. ×80.
9. Detail of Fig. 8, showing earlier aperture (compare with Fig. 7). ×250.
10. Surface microtopography viewed tangentially, showing microgranular outer veneer and pores. Sample OK–14. ×5000.

Figs. 11, 12. *Globocassidulina oriangulata* Belford.

11. Detail of final aperture, showing cristate tooth (CT), sulcus (S), lip (L), and secondary tongue (ST). G=gap. Note tripartite aperture. Sample MM–3. ×300
12. Embedded and opened specimen in horizonal view. Note developmental mode of apertural internal modification. Sample MM–3. ×140.

Plate 17

(All figures are scanning electron micrographs)

Figs. 1, 2. *Globocassidulina oriangulata* Belford.

1. Detail of penultimate aperture, showing internal structure. Note primary tongue (PT) adhering to anterior corner of preceding basal apertural branch. CT=copula, Lg=ledge, L=lip, ST=secondary tongue. The same sample as Pl. 16, fig. 12. ×500.

2. Surface microtopography of earlier portion, showing imbricated structure. Pores slightly depressed. Sample, Recent beach sand in Nabeta cove, Izu Peninsula. ×300.

Figs. 3–7. *Globocassidulina tsuchidai* Nomura, sp. nov. .....p. 70

3. Tangential view. Note rugged surface in earlier portion. Sample MU–5. ×150.

4. Detail of apertural view, showing cristate tooth (CT), sulcus (S), lip (L), apertural flap (AF), apertural ridge (AR), and faint apertural grooves. Sample MU–5. ×500.

5. Embedded and opened specimen, showing inner structure. Note copula (CP) adhering to preceding lip. Sample MU–5. ×300.

6. Surface microtopography on penultimate chamber, showing very slightly etched outer veneer and rounded pores (compare with Fig. 7). The same sample as Fig. 3. ×5000.

7. Surface microtopography on earlier portion, showing vermiculated structure and various types of pores in depressions (compare with Fig. 6). The same sample as Fig. 3. ×1500.

Fig. 8. *Globocassidulina decorata* (Sidebottom).

Detail of final and penultimate aperture, showing cristate tooth (CT), sulcus (S), lip (L), and apertural ridge (AR). Sample MU–1. ×350.

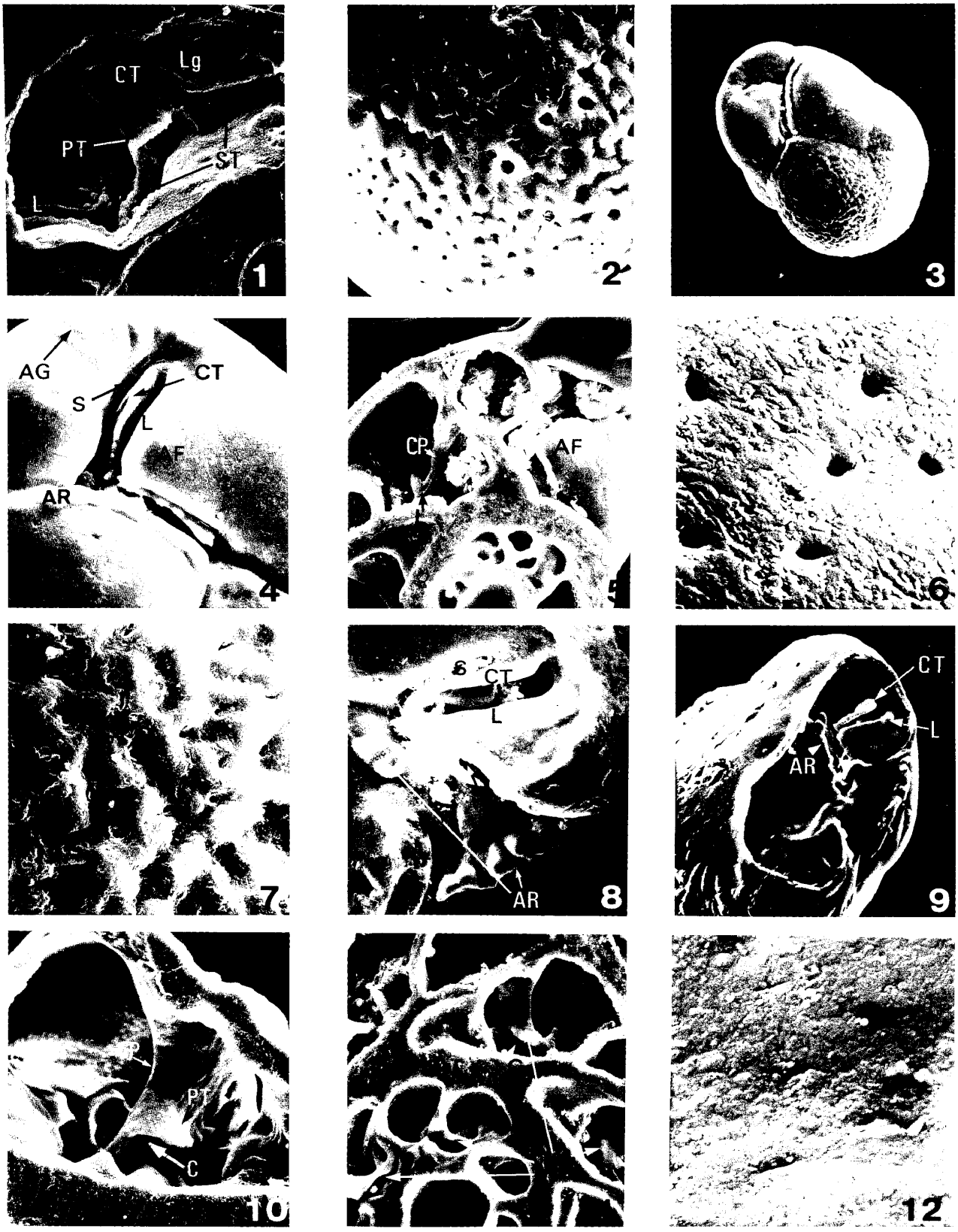
Figs. 9–12. *Globocassidulina nojimana* (Kuwano).

9. Profile view of specimen with broken final chamber, showing apertural internal modification and penultimate aperture. Note copula adhering to corner of preceding basal apertural branch. CT=cristate tooth, L=lip, AR=apertural ridge. Sample MU–2. ×150.

10. Detail of final aperture, showing copula (CP) adhering to preceding lip (L). C=cavity, PT=primary tongue. Sample MU–2. ×500.

11. Embedded and opened specimen, showing inner structure. Note developmental mode of primary tongue (PT). C=cavity. Sample MU–2. ×500.

12. Surface microtopography of penultimate chamber, showing microgranular outer veneer and slit-shaped pores in a parallel direction. Sample MU–2. ×5000.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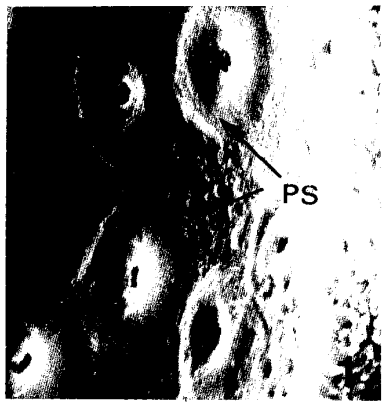
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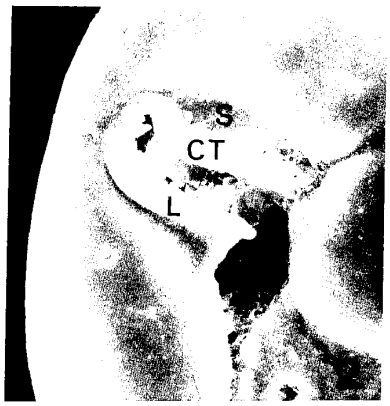
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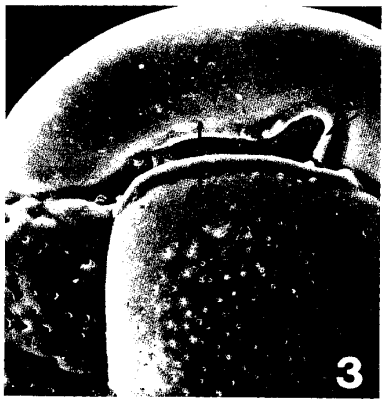
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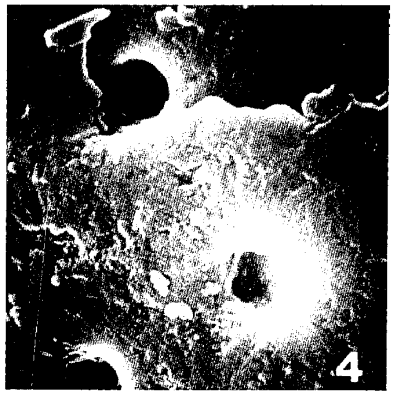
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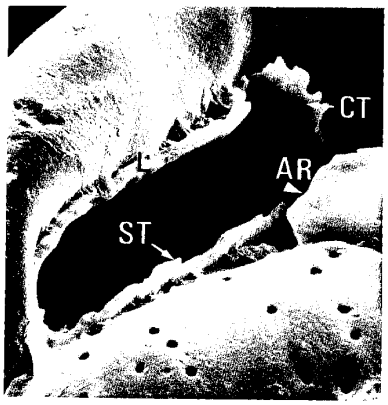
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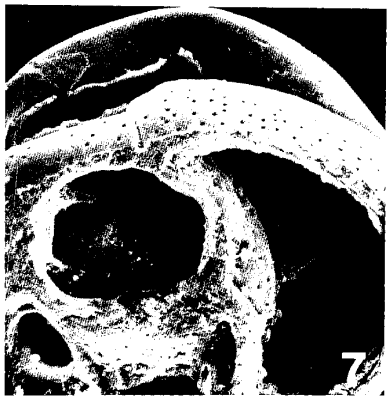
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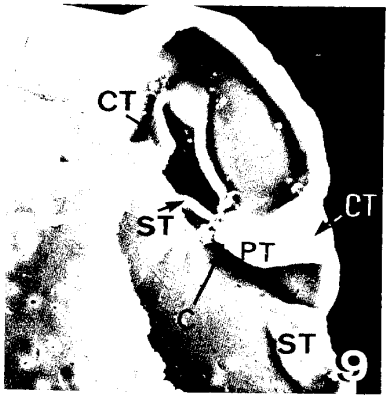
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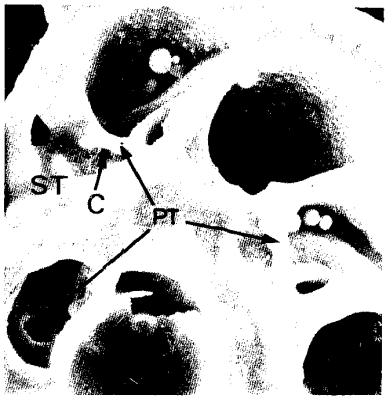
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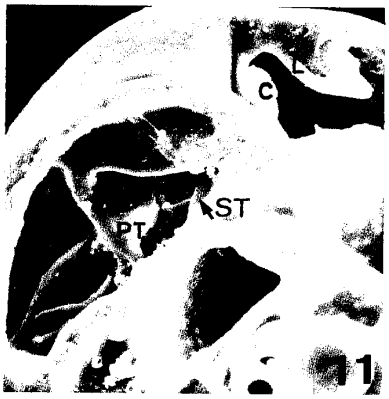
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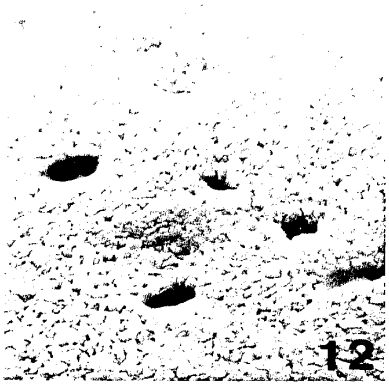
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Plate 18

(All figures are scanning electron micrographs)

Fig. 1. *Globocassidulina nojimana* (Kuwano).
Detail of antipenultimate chamber, showing inner test surface. Note pore swell (PS) and pore terrace. Sample MU–2. ×1500.

Fig. 2. *Globocassidulina okinawaensis* (LeRoy).
Detail of final aperture, showing tripartite feature accompanied with cristate tooth (CT), sulcus (S), and protrudent lip (L). Sample OK–22. ×450.

Fig. 3–5. *Globocassidulina crassa* (d'Orbigny).
3. Detail of final aperture, showing tripartite aperture consisting of long narrow basal branch and low areal branch. L=lip, CT=cristate tooth, AR=apertural ridge. Sample BS–3. ×300.
4. Surface microtopography, showing rounded pores and calcitic growth lamella exfoliated. Sample BS–4. ×5000.
5. Embedded and opened specimen, showing horizontal view. Note developmental mode of aperture. Sample BS–3. ×150.

Figs. 6, 7. *Globocassidulina patula* (Cushman).
6. Detail of final aperture, showing large and broad basal aperture accompanied with cristate tooth (CT), lip (L), and secondary tongue (ST). Areal apertural branch very low. AR= apertural ridge. Sample OK–14. ×250.
7. Embedded and opened specimen, showing internal structure of earlier chambers. Sample OK–14. ×200.

Figs. 8–12. *Globocassidulina brocha* (Poag).
8. Detail of final aperture. CT=cristate tooth, L=lip, ST=secondary tongue, AR= apertural ridge. Sample MU–4. ×400.
9. Profile view of specimen with broken final chamber, showing apertural internal modification and penultimate aperture. Note copula adhering to anterior corner of preceding basal apertural branch. CT=cristate tooth, PT=primary tongue, ST=secondary tongue, C=cavity, L= lip. Sample MU–7. ×300.
10. Embedded and opened specimen, showing earlier apertural structure. Note rudimentary primary tongue (PT) with cavity, and secondary tongue (ST). Sample MU–4. ×500.
11. Detail of opened specimen, showing final aperture with cristate tooth (CT) and lip (L), and penultimate aperture viewed from interior. Pt=primary tongue, ST=secondary tongue. Compare with nepionic aperture. Sample MU–7. ×400.
12. Surface microtopography, showing microgranular outer veneer and rounded pores. Sample MU–4. ×5000.

Plate 19

(All figures are scanning electron micrographs)

Figs. 1, 2. *Globocassidulina jamesoni* (McCulloch).

1. Embedded and opened specimen in horizontal view. Sample MM–1. ×200.

2. Detail of Fig. 1, showing inner structure of earlier chambers. Note simple apertural modification without internal free part. ×500.

Figs. 3–6. *Globocassidulina neobrocha* Nomura, sp. nov. .....p. 67

3. Apertural view, showing nodose lip (L), secondary tongue (ST), and protrudent cristate tooth (CT). Sample OG–21. ×400.

4. Profile view of specimen with broken final chamber, showing internal modification of final aperture as well as a penultimate aperture. Note primary tongue (PT) of final aperture adhering to anterior corner of preceding aperture. CT=cristate tooth, L=lip, ST=secondary tongue. Sample OG–21. ×400.

5. Embedded and opened specimen, showing internal structure. Note development of primary tongue (PT). ST=secondary tongue, L=lip, CT=cristate tooth. Sample OG–21. ×200.

6. Surface microtopography on earlier chamber, showing rounded pores. Note that larger opening with striations is boring. Sample OG–21. ×1000.

Figs. 7–9, 11. *Globocassidulina crenulata* Nomura, sp. nov. .....p. 60

7. Embedded and opened specimen, showing developmental mode of apertural internal modification. Sample OK–21. ×130.

8. Detail of Fig. 7, showing rudimentary primary tongue (PT) and cavity (C) of penultimate and earlier apertures. L=lip, ST=secondary tongue. ×500.

9. Surface microtopography on earlier chambers, showing rugged outer veneer and various types of pore shapes. Sample OK–21. ×1500.

11. Tangential view of Fig. 7. Note elongate oval apertures in earlier stage, and internal structure. ×150.

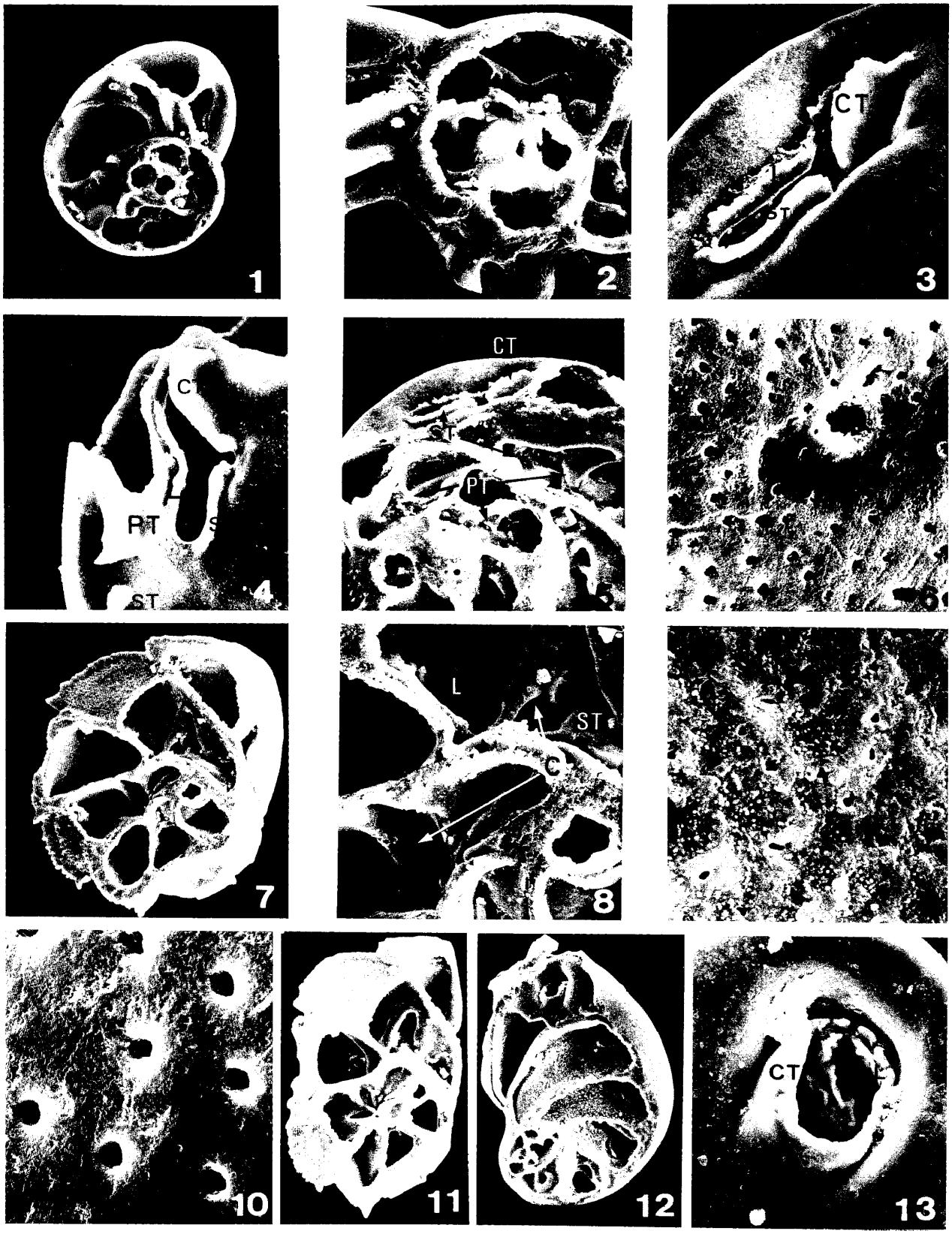
Fig. 10. *Globocassidulina patula* (Cushman).

Surface microtopography on earlier chamber, showing smooth outer veneer and rounded pores. Sample OK–14. ×5000.

Figs. 12, 13. *Evolvocassidulina eadei* Nomura, sp. nov. .....p. 77

12. Embedded and opened specimen, showing ontogenetic development of aperture. Sample OK–15. ×100.

13. Detail of final aperture, showing simple modification. Note lip (L) and cristate tooth (CT) not conspicuously differentiated. Sample OK–15. ×500.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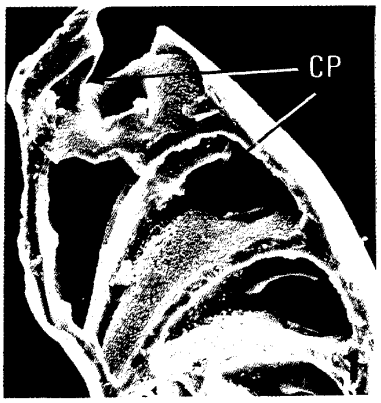
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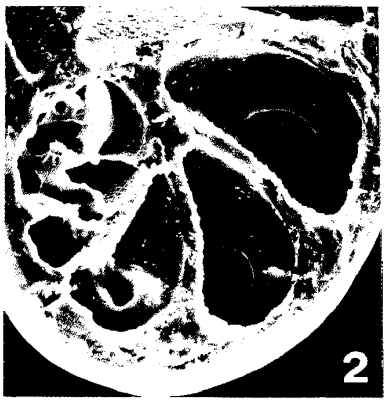
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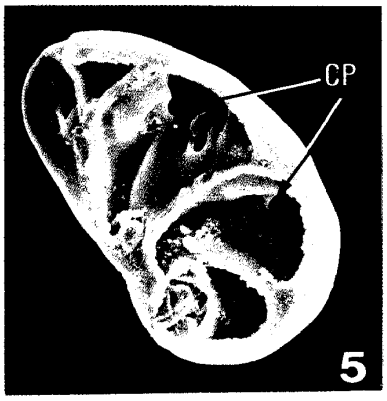
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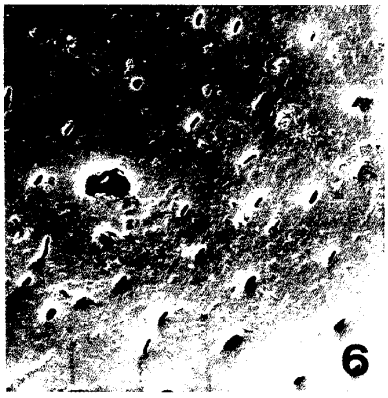
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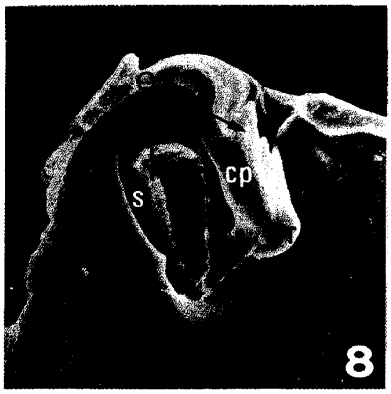
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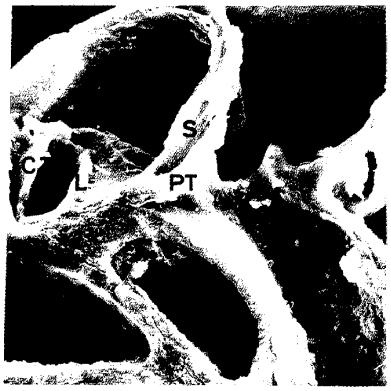
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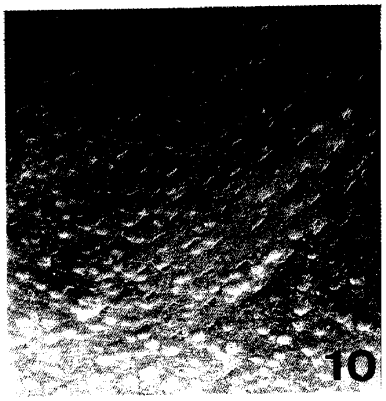
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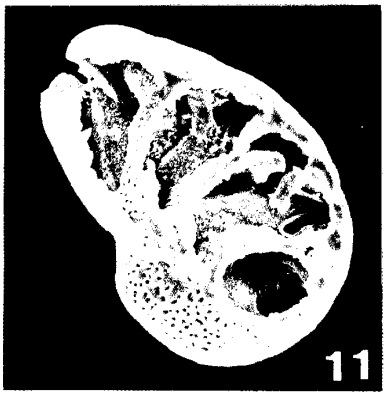
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CT
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Plate 20

(All figures are scanning electron micrographs)

Figs. 1–3 *Evolvocassidulina eadei* Nomura, sp. nov. ..... p. 77

1. Detail of Pl. 19, fig. 12, showing copula (CP) without internal free part. ×150.
2. Detail of Pl. 19, fig. 12, showing simple internal structure. ×270.
3. Surface microtopography on earlier chamber, showing rounded pores. Sample OK–15. ×1500.

Figs. 4–7. *Evolvocassidulina kuwanoi* (Matoba).

4. Detail of penultimate aperture, showing protruding cristate tooth (CT), sulcus (S), and lip (L). Sample CH–8. ×750.
5. Embedded and opened specimen, showing horizontal view. Note simple internal modification without primary tongue. CP=copula. Sample CH–8. ×230
6. Surface microtopography on earlier chamber, showing slit-shaped pores. Semi-rounded pores are boring. Sample CH–8. ×1500.
7. Etched inner test surface, showing crystal units consisting of crystal elements. Note irregularly overlapped crystal units and diverging crystal elements. Inner veneer completely dissolved. Sample BS–13. ×1500.

Figs. 8–10, 12. *Evolvocassidulina belfordi* Nomura, sp. nov. ..... p. 79

8. Detail of penultimate apertures and internal modification of final aperture, showing cristate tooth (CT), copula (CP), primary tongue (PT), lip (L), and sulcus (S). Note copula adhering to basal part of preceding aperture. Sample OK–16. ×230.
9. Detail of antipenultimate apertural modification and earlier apertures, showing horizontal view. S=sulcus, PT=primary tongue, L=lip, CT=cristate tooth. Sample OK–11. ×500.
10. Surface microtopography of earlier chamber, showing slit-shaped pores arranged in a parallel direction. Note numerous lumps (lower side). Sample OK–16. ×500.
12. Detail of last two pairs, showing horizontal view. Note cristate tooth (CT), primary tongue (PT), sulcus (S), and position of copula. Sample OK–11. ×400.

Fig. 11. *Evolvocassidulina brevis* (Aoki).

Opened specimen, showing apertural internal modification. Sample BS–11. ×140.

Plate 21

(All figures are scanning electron micrographs)

Figs. 1–5. *Evolvocassidulina brevis* (Aoki).

1. Open specimen, showing nepionic oval aperture. Sample BS–11. ×300.
2. Detail of apertural view, showing cristate tooth (CT) and lip (L). Sample AR–6. ×720.
3. Detail of pore on earlier chamber, showing pore constrictions (Pc) and irregular boundaries of crystal elements. Outer veneer dissolved. Sample AR–6. ×5000.
4. Surface microtopography on earlier chamber, showing large rounded pores. Note interpore region inflated. Sample BS–11. ×500.
5. Surface microtopography on final chamber, showing rounded pores and irregular boundaries between crystal units (CU). Note pore margin flush with surface. Outer veneer dissolved. Sample AR–6. ×5000.

Figs. 6–10. *Burseolina pacifica* (Cushman).

6. Detail of final aperture, showing apertural flap (AF) and lip (L). Sample OK–23. ×130.
7. Detail of penultimate aperture with dissected final chamber, showing lip (L), cristate tooth (CT), sulcus (S), and apertural ridge (AR). Note lip-like cristate tooth upside down. Sample OK–14. ×120.
8. Tangential view of dissected final chamber, showing apertural flap (AF). Sample OK–14. ×70.
9. Detail of apertural structure of final chamber and preceding aperture, showing developmental mode of apertural modification. Note copula adhering to preceding apertural flap. S=sulcus, CT=cristate tooth, L=lip, AF=apertural flap. Sample OK–14. ×200.
10. Detail of internal structure, showing earlier apertures. L=lip, C=cavity, PT=primary tongue, CP=copula. Sample OK–14. ×500.

Figs. 11, 12. *Burseolina bullaeformis* Nomura, sp. nov. .....p. 90

11. Detail of final aperture, showing apertural flap (AF), lip-like cristate tooth (CT), and sulcus (S). Sample BS–7 (A). ×500.
12. Embedded and opened specimen, showing internal view of earlier apertures. Note copula (CP) and cavity (C). Sample BS–7 (A). ×400.


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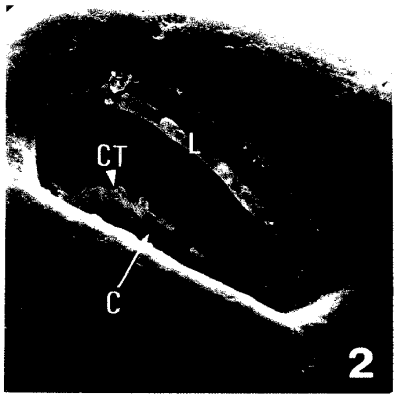
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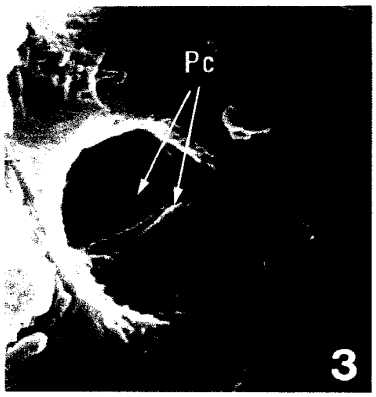
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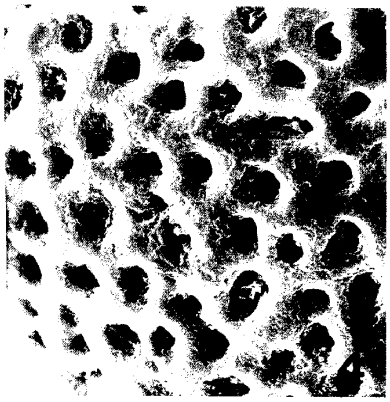

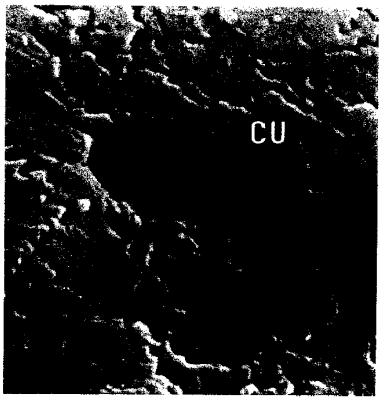
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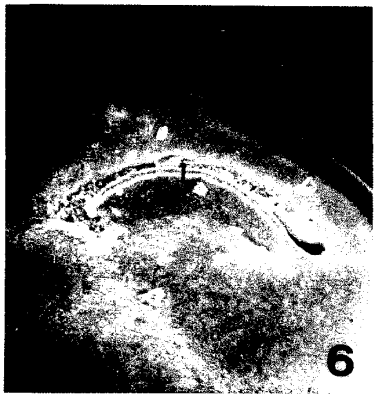
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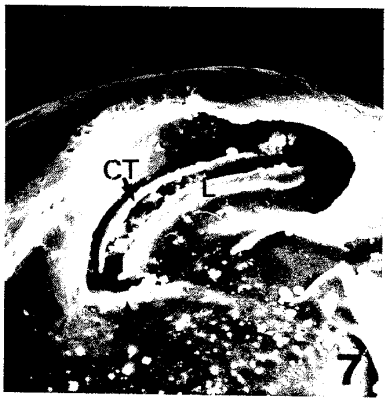
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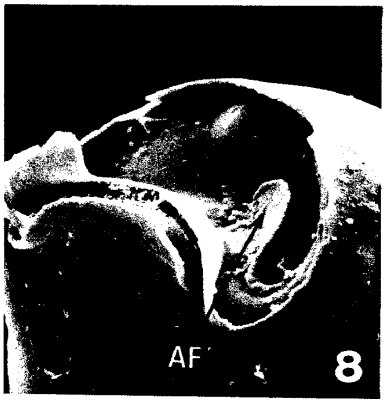
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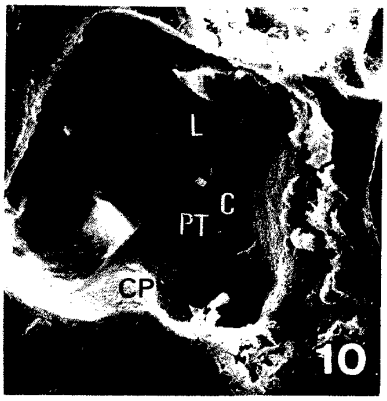
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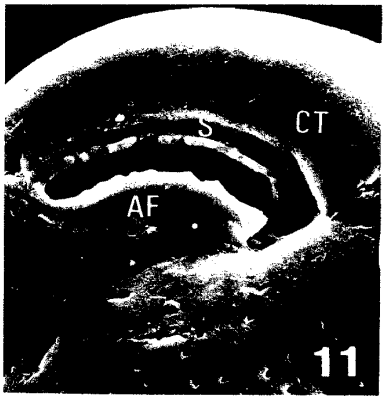
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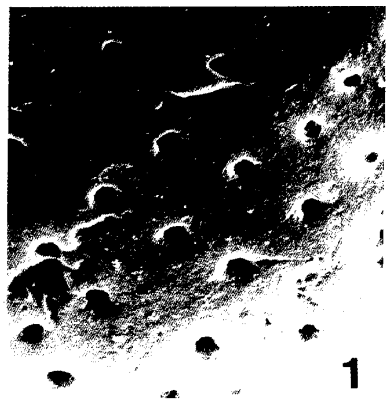
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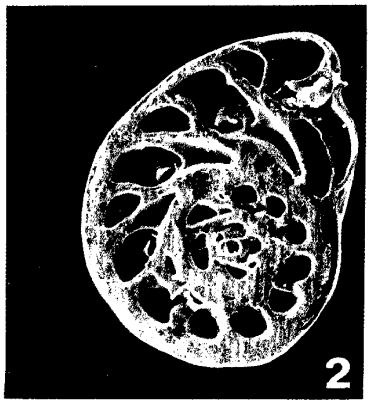
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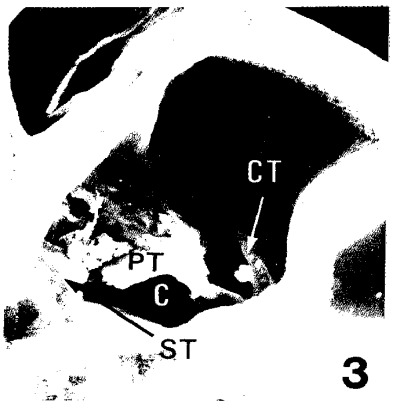

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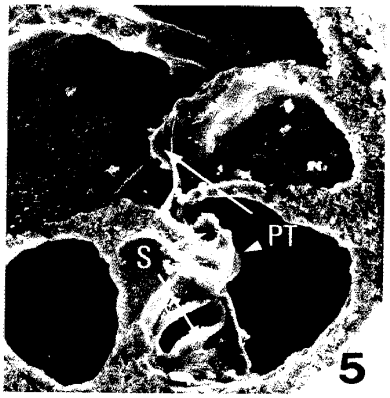

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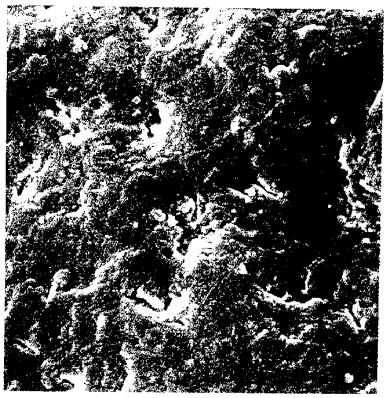

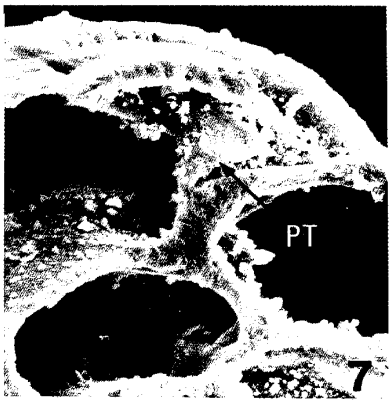

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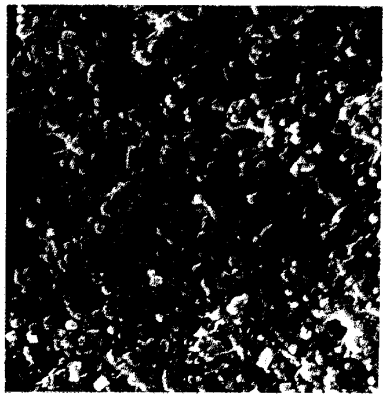

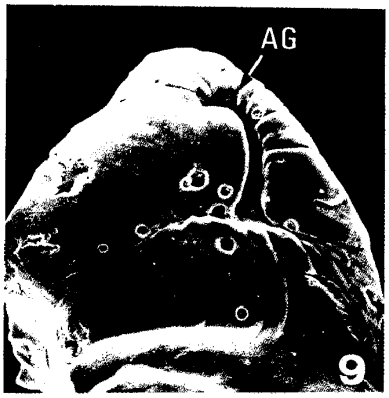

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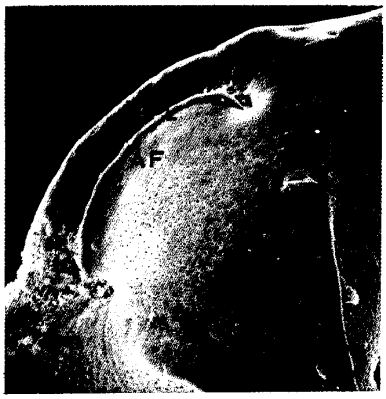
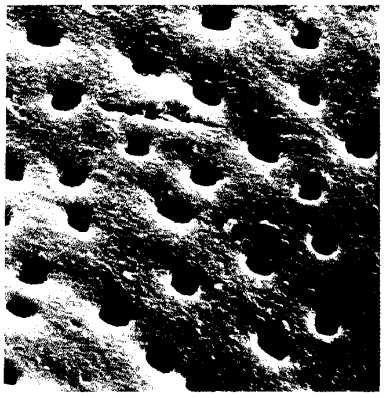




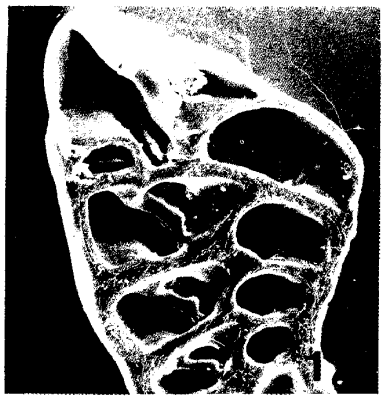


Plate 22

(All figures are scanning electron micrographs)

Fig. 1. *Burseolina bullaeformis* Nomura, sp. nov. ..... p. 90
Surface microtopography on earlier chamber, showing rounded pores. Sample BS–7 (A). ×1500.

Figs. 2–6. *Globocassidulina ryukyuensis* Nomura, sp. nov. ..... p. 75

2. Embedded and opened specimen, showing inner structure. Note ontogeny of primary tongue. Sample OK–3. ×70.

3. Internal view of antipenultimate aperture, showing primary tongue (PT) and cavity (C). Secondary tongue (ST) formed on inner side of preceding septal chamber wall (right side). The same sample as Fig. 2. ×350.

4. Internal view of earlier aperture, showing primary tongue (PT), cavity (C), and internally protrudent secondary tongue (ST). Sample OK–3. ×300.

5. Tangential cross section, showing internal structure of earlier apertures. Note developmental mode of toothpate adhering to basal portion of preceding aperture. S=sulcus, PT=primary tongue. Sample OK–3. ×200.

6. Surface microtopography on earlier chamber, showing slightly rugged outer veneer with slit-shaped pores. Sample OK–3. ×3000.

Fig. 7. *Ehrenbergina bosoensis* Takayanagi.
Embedded and opened specimen, showing cristate tooth (CT). Note cristate tooth completely concealed by apertural flap. Small calcitic materials on wall are of crystal overgrowth. Sample BS–7(A). ×250.

Figs. 8, 9. *Ehrenbergina bosoensis decorata* Takayanagi.

8. Surface microtopography on final chamber, showing granular crystallites of outer veneer and small pores. Sample BS–2. ×4000.

9. Detail of final aperture, showing tangential view. Note apertural grooves (AG). Rounded openings are boring. AF=apertural flap. Sample BS–2. ×100.

Figs. 10–12. *Ehrenbergina carinata* Eade.

10. Detail of final aperture, showing apertural flap (AF) and lip (L). Sample OK–23. ×150.

11. Surface microtopography on final chamber, showing rounded pores. Sample OK–23. ×1500.

12. Embedded and opened specimen, showing tangential view. Note developmental mode of toothplate. Sample OK–23. ×100.

Plate 23

(All figures are scanning electron micrographs)

Figs. 1–4. *Ehrenbergina carinata* Eade.

1. Tangential view of final and penultimate apertures, showing cristate tooth (CT) and primary tongue (PT). Note copula (CP) adhering to preceding lip (L). Sample OK–23. ×300.
2. Detail of final toothplate. Note serrated cristate tooth (CT) and copula (CP) adhering to preceding lip (L). Sample OK–23. ×500.
3. Dissected peripheral spine of final chamber, showing spine hollow (SH). Sample OK–23. ×500.
4. Detail of earlier portion of Pl. 22, fig. 12, showing cristate tooth (CT) and cavity (C). Note anterior end of primary tongue adheres to chamber wall in earlier stage. ×350.

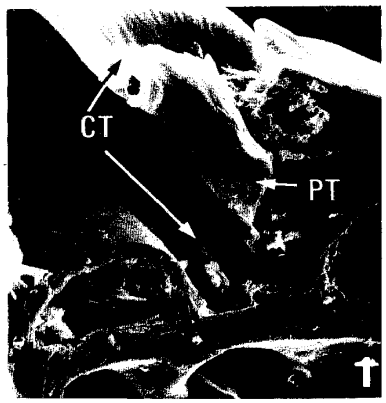
Fig. 5. *Ehrenbergina crispata* Nomura, sp. nov. .....p. 93
Ventral view of final aperture, showing semi-circular apertural flap (AF) with lip and apertural grooves (AG). Sample OK–1. ×100.

Figs. 6–9. *Cassidulina carinata* Silvestri.

6. Embedded and opened specimen, showing vertical view. Sample OK–7. ×120.
7. Apertural view, showing lip (L) and apertural plate (AP). Sample OK–20. ×230.
8. Embedded and opened specimen, showing apertural plate (AP) and lip (L). Apertural plate formed in peripheral margin of preceding chamber. Lip formed by turning over septal chamber wall. Sample OK–7. ×280.
9. Detail of pore on earlier chamber near umbilicus, showing funnel-shaped opening. Note pore constriction (Pc). Sample OK–20. ×5000.

Figs. 10–12. *Cassidulina norvangi* Thalmann.

10. Apertural view, showing apertural plate (AP). Sample AR–5. ×400.
11. Detail of specimen with broken final chamber, showing apertural plate (AP) formed in peripheral margin of preceding chamber and penultimate apertural plate. Note calcitic growth lamella exfoliated (arrow). Sample OG–19. ×500.
12. Internal view of penultimate aperture, showing apertural plate (AP) connected with ledge (Lg) on posterior side (right side). Sample OG–19. ×500.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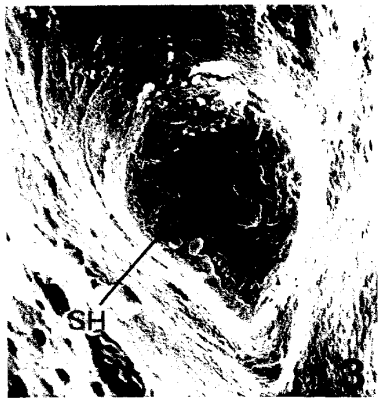
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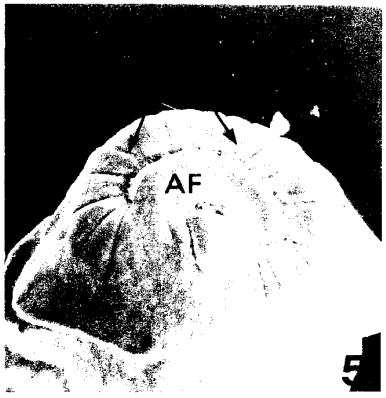
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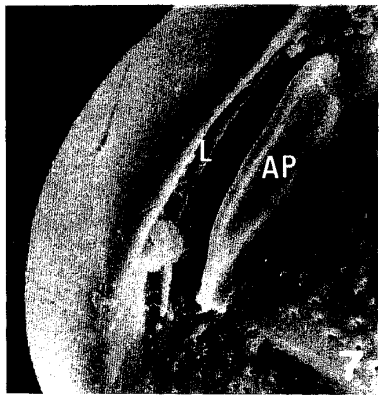
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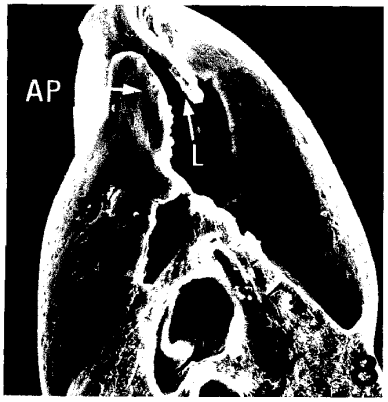
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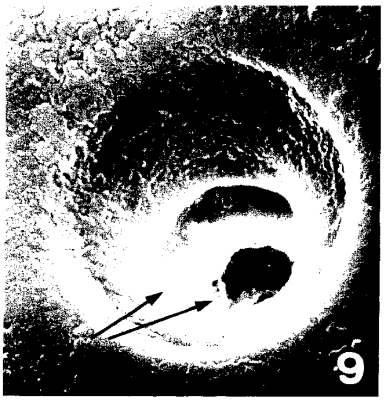
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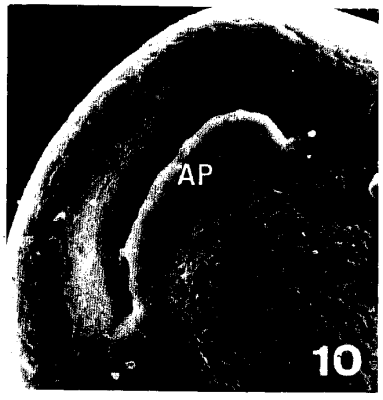
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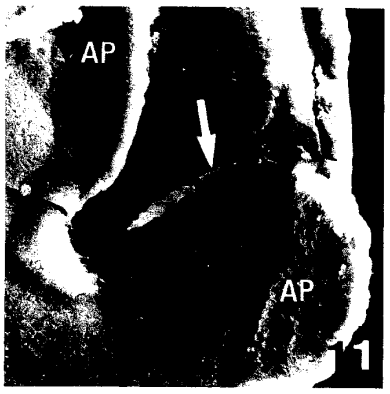
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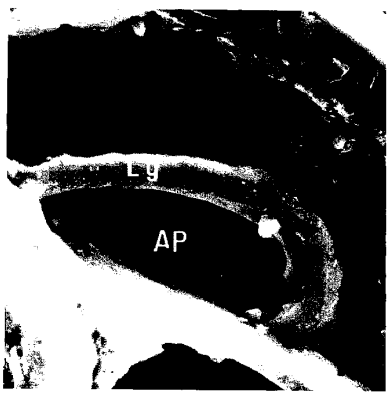
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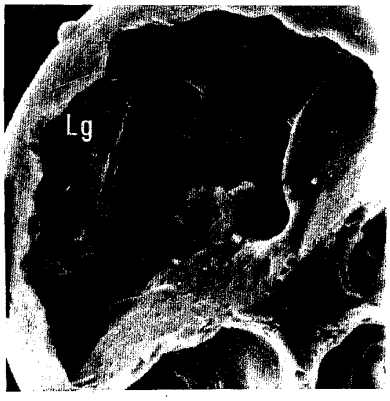
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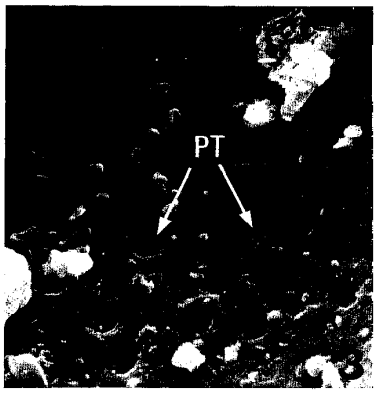
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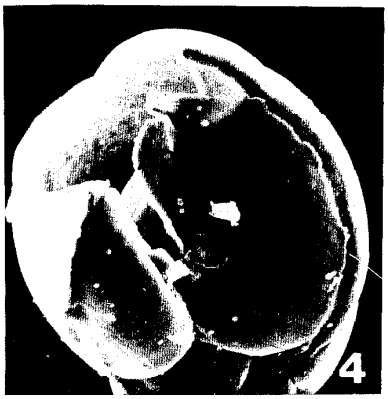
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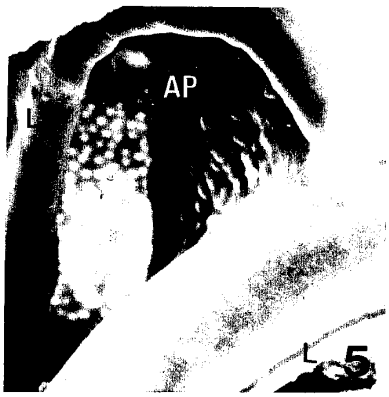
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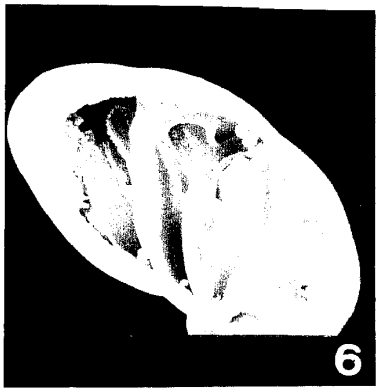
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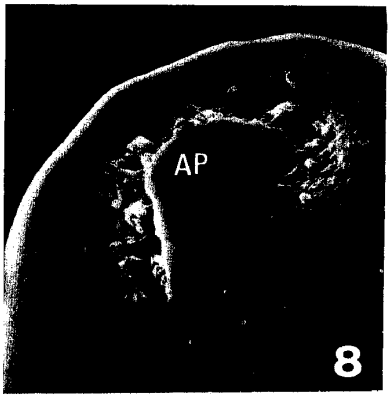
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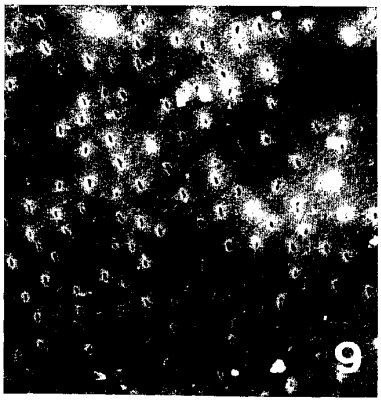
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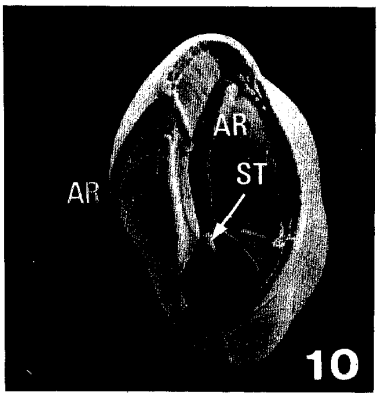
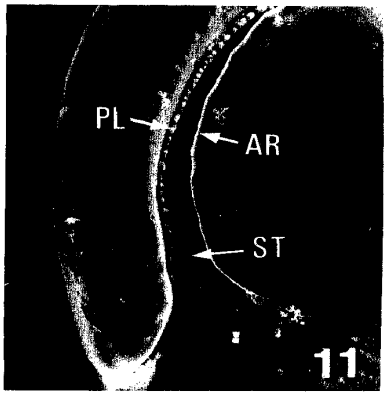

AR
AR
ST
10


PL
AR
ST
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12

Plate 24

(All figures are scanning electron micrographs)

Figs. 1–3. *Cassidulina norvangi* Thalmann.

1. Embedded and opened specimen, showing internal view of final chamber. Note apertural plate (AP) and ledge (Lg). Sample OG–19. ×350.

2. Surface microtopography on earlier chamber, showing irregular boundaries of crystal units. Note that pores are placed in crystal units and in boundaries of crystal units. Somewhat tabular crystal units are overlapped with each other in right side. Microgranular outer veneer completely dissolved. Sample AR–5. ×1500.

3. Microtopography of inner test surface, showing pitted pores with pore terrace. Sample AR–5. ×1500.

Figs. 4, 5. *Lernella inflata* (LeRoy). .....p. 86

4. Edge view of specimen with broken final chamber, showing apertural plate (AP) obliquely adhering to periphery of preceding chamber. Sample OK–10(B). ×150.

5. Internal view of apertural plate (AP), showing mammillated inner test surface. Lg=ledge. Sample OK–10(B). ×500.

Figs. 6, 7. *Lernella seranensis* (Germeraad).

6. Embedded and opened specimen, showing ontogenetic development of apertural plate. Sample OK–16. ×130.

7. Detail of earlier apertures. Apertural plate is cristate tooth in younger stage. Sample OK–6. ×500.

Figs. 8. 9. *Lernella ogasawarai* Nomura, sp. nov. .....p. 88

8. Apertural view, showing apertural plate (AP) concealing apertural foramen. Sample OK–13. ×500.

9. Surface microtopography on antipenultimate chamber, showing small oval pores tending to slit shape. The same sample as Fig. 8. ×1500.

Figs. 10–12. *Paracassidulina sagamiensis* (Asano and Nakamura).

10. Edge view of specimen with last pair, showing apertural ridge (AR) and secondary tongue (ST). Sample KR–5. ×100.

11. Apertural view, showing nodose pseudolip (PL), apertural ridge (AR), and secondary tongue (ST). Sample KR–5. ×220.

12. Embedded and opened specimen, showing ontogenetic development of aperture. Note anterior ledge attached to previous whorl, and posterior ledge attached to septal chamber wall. Sample KR–5. ×100.

Plate 25

(All figures are scanning electron micrographs)

Figs. 1, 2. *Paracassidulina sagamiensis* (Asano and Nakamura).

1. Surface microtopography on antipenultimate chamber, showing slit-shaped pores arranged in one direction. Sample KR–5. ×1500.

2. Surface microtopography of final chamber, showing granular outer veneer. Note blind pores. Sample KR–5. ×5000.

Fig. 3. *Paracassidulina nipponensis* (Eade).

Embedded and opened specimen, showing ontogenetic development of aperture. Sample MM–5. ×100.

Figs. 4–6. *Paracassidulina miuraensis* (Higuchi).

4. Embedded and opened specimen, showing ontogenetic development of aperture. Lg=ledge. Sample MU–5. ×250.

5. Surface microtopography on earlier chamber, showing rounded pore as well as oval pore, and outer veneer. Sample MU–5. ×7500.

6. Apertural view of specimen with broken final chamber, showing apertural ridge (AR) and pseudolip (PL). Note anterior chamber wall adhering to preceding septal chamber wall. Sample MU–5. ×200.

Fig. 7. *Paracassidulina nabetaensis* Nomura, sp. nov. .....p. 98

Detail of last aperture, showing apertural ridge (AR) and apertural grooves (AG). Sample, Recent beach sand in Nabeta cove, Izu Peninsula. ×300.

Fig. 8. *Paracassidulina nipponensis* (Eade) *terebra* Nomura, subsp. nov. .....p. 97

Surface microtopography on earlier chamber, showing slit-shaped pores somewhat irregularly arranged. Sample BS–6. ×1500.

Figs. 9–11. *Paracassidulina quasicarinata* Nomura, sp. nov. .....p. 100

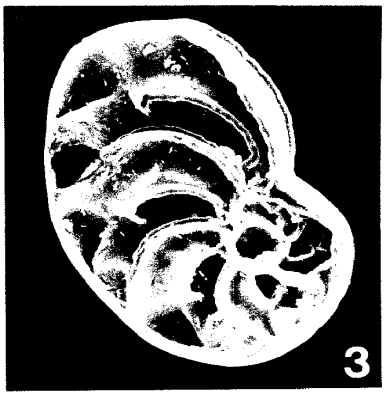
9. Apertural view of specimen with broken final chamber, showing apertural ridge (AR). Sample MU–1. ×250.

10. Tangential view of specimen with numerous borings. Sample MU–1. ×170.

11. Embedded and opened specimen, showing apertural ridge (AR) and ledge (Lg). Sample MU–1. ×350.

Fig. 12. *Hastilina subtenuis* Nomura, sp. nov. .....p. 83

Detail of penultimate aperture, showing cristate tooth (CT) and copula without internal free part. Note copula adhering to terminal portion of preceding chamber. L=lip. Sample OK–10(A). ×150.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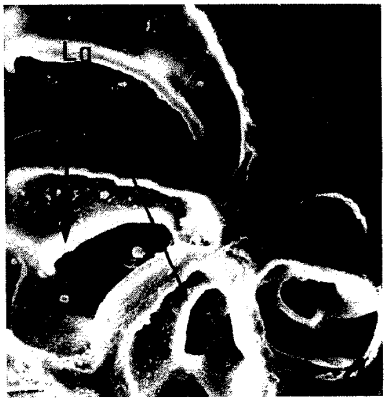
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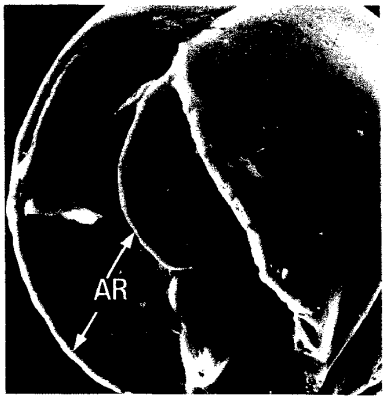
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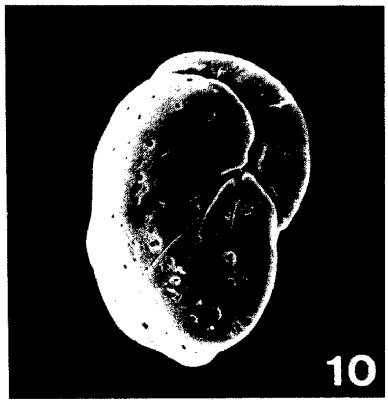
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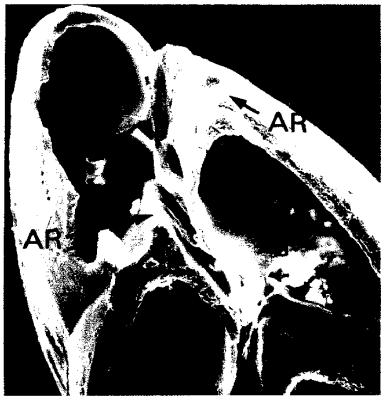
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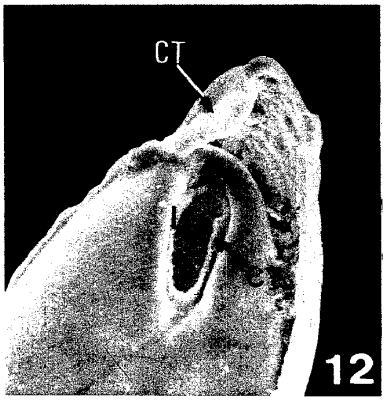
AR


CT
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